TRANSACTIONS OF

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SECTION IV

GEOLOGICAL SCIENCES

INCLUDING MINERALOGY

THIRD SERIES—VOLUME LI—SECTION IV

JUNE, 1957

OTTAWA

THE ROYAL SOCIETY OF CANADA

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SECTION FOUR

PRESIDENTIAL ADDRESS

Fundamental Geological Research on Ore Deposits

H. C. GUNNING, F.R.S.C.

ABSTRACT

A plea is made for national co-ordination of our scientific investigation of mineral deposits. We have the men and the tools but their efforts, through lack of co-ordination and concentration, have failed to give us the complete data that are necessary for a proper understanding of any mineral deposit. Until we have these data our skill in mineral exploration is not apt to attain the standards required by the rapidly increasing rate of depletion of our mineral resources.

THIS Seventy-Fifth Annual Meeting of the Royal Society of Canada centres around a series of symposia under the title "Our Debt to the Future." The discussions focus attention upon the evaluation and wise use of Canada's resources, human and material. The Society has requested that each Section, in so far as it can, arrange for sectional contributions that relate to the general topic. It seems fitting, therefore, that my address should deal with fundamental research on mineral deposits.

I wish to make it clear at the beginning that I draw a clear distinction between *geological* research and *geochemical* research or *geophysical* research. I might put it this way:

The programme I am suggesting would be aimed directly toward increasing our efficiency in the discovery of ore deposits and therefore would be based on and guided by field studies of ore deposits and mining districts. It would require the co-operative work of chemists and geochemists, physicists and geophysicists, and no doubt of other specialists, making use of all the modern tools that can be put at its disposal. But the basic objective would be a better, if possible a complete, understanding of the environment of ore deposits, in the belief that until we know this in much greater detail than we do at present, our search for new deposits is apt to be relatively inefficient. The implication is that the study of ore deposits is still essentially a field science and that complete scientific study of them, and the districts in which they have been found, will continue for many years to make major contributions to the science of ore-finding.

The general problem was presented this spring to the National Advisory Committee on Research in the Geological Sciences. A sub-committee has been set up to investigate the problem and, if deemed advisable, to recommend ways and means of solving it. The Fellows of this Section of the Royal Society could be of great assistance by directing comments or suggestions to me or to other members of the committee.

The suggestion is that a small fraction of the effort that is at present being expended by companies, by government bureaus, by university departments and by individuals should be co-ordinated through a national committee and concentrated on some really exhaustive studies of one or more mineral deposits. Perhaps only one mineral deposit or mining district could be attempted for a start, but the more the better. The important thing is that some ore deposits, and mineral districts, should be given the complete scientific treatment.

None of the studies that are envisaged is new. All of them have been, and are being, made today with great skill and you will find many excellent accounts of them in the literature, or records of them in company files. Nor could all of them be mentioned here because it would require the co-operation of several specialists, each more competent than this writer, to formulate the programme for any deposit or district. However, a few items may be mentioned to clarify the issue.

Accurate records of changes in mineralogy in ore deposits would be of major importance. The information should be as nearly statistically correct as possible if it is to be reliably significant. This would necessitate systematic recording throughout a mine, not merely visual observations, as is the usual thing in most well-organized mines today, but on a more strictly quantitative basis, based on more complete chemical analyses than are usual. In some mines more than others, depending on the composition of their ore, a good deal of special sampling would be required. The analyses would have to be recast to mineral composition and this might necessitate more petrographic study than is common in most mines. These studies would be carried as far as mine openings or the surface permitted beyond the actual limits of ore-bodies. Accurate studies of changes in mineralogy below, above, and beyond ore shoots are exceedingly rare and yet many mines have bottomed a good many ore shoots during their life and have developed many horizons above "blind" shoots. The sum total of this kind of information for an exhausted mine would add up to the kind of data on zonal distributions that are seldom, if ever, available. Perhaps Butte, or some of the Michigan copper deposits, could be cited as near rivals, and some of our own heavy sulphide deposits, like Noranda or some of the Sudbury ores, may have been studied in this way, with the records available in company files. Even if the data are available, time and ability to analyse them are not very easily come by and it is debatable if many individual companies could be expected to find the time and money that would be necessary to publish the material or even to make it readily available in open file. Would any of us doubt that the results eventually would be of major help in mineral exploration and in the determination of, say, depth possibilities for ore?

Another important item would be the thorough study of structure throughout our test mine. Canadian geologists are already expert at this. The structures that control the ore *and* the internal structures of the ore—banding, brecciation, comb-structure, grain size and the like—would be included, and would need to be correlated with the mineralogical variations.

The mineralogical studies mentioned above should include, of course, studies of fluid inclusions and systematic studies of polished surfaces of ore minerals. Someone, throughout our study, would be detailed to look for and record any evidence of the direction of flow of the mineralizing fluid. We speak quite readily of the ascent of these fluids but how often do we *know*, at any particular spot, whether they came up, down, or horizontally? Some good work in this field has been published recently, but some of the earlier work by Newhouse and others seems to have been nearly forgotten.

So far, only the actual mineral deposit, be it vein, lode or replacement body, has been considered. But our studies, to be at all complete, must include careful field study of the environment as far as possible beyond the deposit itself. Structural, mineralogic and petrographic investigations, supported by adequate chemical analyses, would be essential until we are sure that we have passed beyond the points where the ore or its generating fluid leaves any trace of change in the country rock. Unfortunately, we are apt to be limited here by mine openings, but there is always the surface, and so, if possible, our test mine should be picked from an area blessed with good surface exposures. Perhaps, when studies of this kind have paid off in dollars and cents by new ore discoveries or greatly reduced exploration costs, we will be able to persuade management to drive a few special openings for scientific study, far beyond or below any ore.

Another special study throughout the life of our mine will centre on the sequence of events. Several special brains will be required to direct this effort. First we must know with precision the paragenesis of the ore and gangue minerals. This in itself will require careful field observation and the collection of many specimens for laboratory studies. The field and laboratory observations will need to be made with a considerable degree of perception and scepticism lest we misinterpret the evidence or apply old rules that are shopworn and unreliable. It would not be surprising if such a study led to some new principles in deciphering paragenetic sequences. Replacement and alteration can produce effects that are uncommonly similar to those of deposition. The whole study will have to be carefully tied to the sequence of structural events, for the timing of structural and mineralizing episodes is believed, with good reason, to be vital in the formation of many ore bodies and in the zonal distribution of minerals. Another concern will be the time relations of our ore and alterations to intrusive rocks. Here we will not be content merely to observe, in the field, the apparent relations at mutual contacts of ore and dyke, or dyke and another intrusive body. We will collect specimens across the contacts, particularly in the case of ore and dykes, and study them under the microscope lest we fail to appreciate that the edge of a dyke can appear chilled against ore and yet show microscopic evidence of having been replaced by, or altered by, the ore.

Finally, in this time study, we will obtain the advice of expert geochemists and geophysicists and we will have made age determinations of all possible minerals, throughout the mine if that is necessary. They will use only material that is collected carefully enough to convince the most sceptical field man,

and only those geophysical methods that are thoroughly reliable. If we cannot find minerals that are sufficiently radioactive to yield uranium-lead measurements we will not forget that micas, which are apt to be widely distributed around the ore, if not in it, hold great promise in this respect. We will have them measured for the K^{40} and A^{40} ratio and again for the rubidium-87 strontium-87 ratio. If the ages by these are the same, within experimental error, we will conclude that the age of that mineral is established, unless some recent studies have shown that mica, as well as feldspar, loses argon by leakage and there is something wrong with the corroborating strontium-87 determination. At any rate, we will persist in having expert advice on this matter of isotopic clocks, and we will use the recommended procedures, but the conclusions will be tested in the strictest way against geological evidence before they are accepted.

Throughout the life of the project we will make systematic tests of all applicable geophysical methods—gravimetric, magnetic, electrical, electromagnetic and, if possible, seismic. We will want to have a battery of recorders around the mine to record the vibrations of heavy blasts. The deposit will be a guinea-pig for these wonderful tools, in the hope that the results will greatly extend their usefulness in exploration and mine development.

As the project continues, we will need a modest staff of experts with time and opportunity to study, analyse and correlate the results and to prepare rather voluminous manuscripts for publication. Lack of these people is undoubtedly one of the greatest single handicaps today in any science, for good information is being collected and published so rapidly that a great deal of it is never properly digested, let alone made available in usable form for the benefit of mankind. Certainly this is true for geology.

It is to be hoped that while all this is going on the owners of the mine will be able to find room in it for their operating personnel. Nevertheless, it is felt that we owe Canada several efforts like this, in an attempt to maintain her mineral resources and to find them in the rapidly increasing quantities that will be needed, because Canada is generously depleting her non-replacable mineral resources at a fantastic rate for the benefit, very largely, of other people. Lest anyone doubt the acceleration of the depletion, let him recall that we are one of the major suppliers of metal to the western world, and that all civilization used more mineral resources in the first quarter of this century than it did in all previous history, and on top of that, in the second quarter, it also used more than in all preceding time. Canada assuredly expects that the geological sciences will do their utmost to delay the ultimate complete depletion of many of her mineral resources.

To all those who wish to give the matter additional thought I commend, most highly, the *Report of the Advisory Committee on Minerals Research.* It was published late in 1956 by the United States National Science Foundation and is available free of charge, as long as copies last, on application to that Foundation, Washington 25, D.C.

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SECTION FOUR

Unusual Pleistocene Fossils from Southeastern Ontario*

FRANCES J. E. WAGNER†
Presented by ALICE E. WILSON, F.R.S.C.

ABSTRACT

Two unusual Pleistocene fossils were found in the Winchester-Cornwall area, Ontario, in the summer of 1956 in excavations resulting from the St. Lawrence Seaway and Power Project operations. These are fossil pearls from *Mytilus edulis* Linné from near Winchester, and glochidia (larvae) of a freshwater mussel from a bog deposit in the vicinity of Moulinette. Both are apparently first records in Canada. The marine-freshwater sequence in the Moulinette bog is also of interest.

TWO interesting fossil discoveries were made in the summer of 1956 in the part of the Winchester-Cornwall area affected by the St. Lawrence Seaway and Power Project operations. One was the discovery of two pearls from near Winchester; the other was of glochidia (larval forms) of a large freshwater pelecypod in the lower part of a bog deposit directly overlying

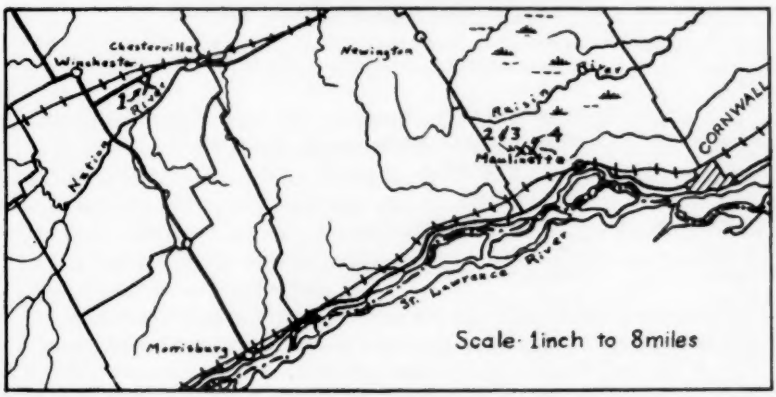

FIGURE 1.—Map of the Winchester-Cornwall area, Ontario, showing the fossil localities.

marine sands in the vicinity of Moulinette. The glacial-marine-freshwater sequence at the glochidia locality and the area immediately surrounding it is also of considerable interest.

*Published with the permission of the Director, Geological Survey of Canada, Department of Mines and Technical Surveys, Ottawa. Photographs in this paper are by courtesy of the Geological Survey of Canada.

†Geologist, Geological Survey of Canada.

Few occurrences of fossil pearls have been reported since the first mention of them by Woodward in 1723. Therefore, any new find deserves to be brought to public attention. The present discovery is apparently the first record of fossil pearls in Canada. Table I, based on Russell (1929) and Berry (1936), presents a summary of the previous discoveries of fossil pearls. The present discovery is included.

TABLE I

DISTRIBUTION OF FOSSIL PEARLS

Location	Species	Age						
		Jurassic	Cretaceous	Eocene	Oligocene	Miocene	Pliocene	Pleistocene
England	*Gryphaea dilatata* (2 occurrences)	x						
	Perna oblonga		x					
	Inoceramus labiatus		x					
	Inoceramus sp. (6 occurrences)		x					
	Pinna affinis			x				
	Ostrea tenera			x				
	Ostrea edulis						x	
United States	*Inoceramus sagensis* var. *quadrans*		x					
	Inoceramus subundatus		x					
	Exogyra texana		x					
	Pteria sp.			x				
	Panope americana					x		
Germany	*Inoceramus goldfussianus*		x					
	Perna sandbergeri					x		
Japan	*Inoceramus* sp.		x					
South-East Africa	*Inoceramus expansus*		x					
Bahamas	*Lima scabra*						x	
Scotland	*Volsella modiolus*							x
Sweden	*Mytilus edulis*							x
Canada	*Mytilus edulis*							x

Two main categories of pearls are recognized: blister pearls and free pearls. Blister pearls form directly on the inside of the shell, whereas the free pearls develop at various places within the mantle and are therefore not attached to the shell. The present specimens are free pearls.

Fossil pearls belonging to both of the major categories have been found. Most of the fossil pearls are free. A few of them are spherical or nearly so, but the majority are of quite irregular shape. A third type of record is the presence of pittings on shells and shell casts. This latter condition is found with some of the Cretaceous species.

The specimens here described were discovered in a sample from the Ball Pit, 3¼ miles east of Winchester on the south side of Highway no. 43 (see Figure 1, Locality 1). The sample was taken by G. W. Brownell of the Hydro-Electric Power Commission of Ontario. Species identified from the sample were: *Mytilus edulis* Linné, *Macoma balthica* (Linné) and *Balanus crenatus* Bruguière. In contrast with most occurrences of it as a fossil, *Mytilus edulis* was very well preserved. Generally only fragments of the shells remain, but here the majority of the valves were entire and a few of the specimens had the valves unseparated. The pearls are obviously from this species. The other pelecypod present, *Macoma balthica*, has a chalky shell and could not have produced a nacreous pearl.

The colour of the pearls is white with a soft lustre, the same as the interior of *Mytilus edulis*. The diameter of the smaller pearl is 0.35 mm., and of the central mass of the larger pearl, 0.4 mm. The larger pearl was lost in an attempt to section it. The smaller one is a perfect sphere; the larger one had an irregular growth on one side of the nearly spherical central mass.

FIGURE 2.—Pearls from *Mytilus edulis* Linné, from sand pit near Winchester, Ontario. × 20. The smaller pearl is G.S.C. hypotype, no. 13, 594.

Loss of the larger pearl did not occur until after one side of it had been ground away and the centre exposed. The interior was seen to be dark for about ⅞ of the diameter, with only a thin nacreous skin. The dark material, which showed concentric layering, was probably conchiolin, a substance forming the external layer in pelecypod shells and frequently found in pearls. The nucleus had apparently been dislodged by the grinding; only a minute cavity was noted in that position.

Fossiliferous freshwater deposits directly overlying fossil-bearing marine sediments have been found in only a few places in the Champlain Sea area. A notable example is the peat bogs in the region around Cornwall. Relocation of the main line of the Canadian National Railways, necessitated by future flooding of the areas close to St. Lawrence River by the Seaway and Power Project, has provided numerous interesting sections that would not otherwise have been opened to study. About three miles northwest of Moulinette, sections show a sequence of till overlain by sand which is in turn overlain by a stiff, jelly-like ooze and peat. The sands contain a marine fauna and the lower part of the bog deposits a freshwater assemblage. Of further interest here was the discovery of glochidia of one of the freshwater mussels, *Anodontoides ferussacianus* (Lea).

Collections from three localities were studied.[3] These localities all lie within the same bog, and the sequence, except for minor variations in the thickness of the units and the texture of the marine sand, is the same in all cases. The excavations for the railway road-bed were cut down to the till. Thickness of the till was not determined. Directly overlying the till is about one foot of marine sand, gravelly at the base at localities 2 and 3, and with considerable clay in it at locality 4. The sand is overlain by from one foot to two feet of a stiff, jelly-like ooze, which in turn is capped by from three to five feet of peat. According to Auer (1930), with reference to the nearby Newington peat bog, the ooze represents an early low-water stage in the formation of the bog.

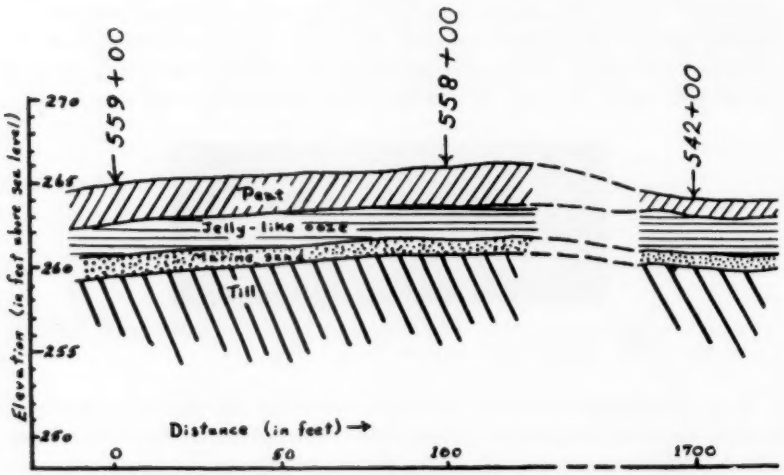

FIGURE 3.—Section through part of the peat bog northwest of Moulinette.

The change from marine to freshwater sediments is abrupt. A certain period of time must have elapsed between the withdrawal of the marine waters and the initiation of freshwater conditions, but no evaluation of it can be attempted from the evidence at hand.

Ten marine and fourteen freshwater species have been identified. Marine species from the sands and gravels include those in Table II. *Macoma balthica* and *Hiatella arctica* are extremely abundant. The assemblages point to shallow water depths, and the small size of *H. arctica* suggests a warming

[3]Fossil localities (see Figure 1):

2. Chainage 559 + 00, C.N.R. relocation. Elevation 265 feet above sea level. Collector G. W. Brownell, Hydro-Electric Power Commission of Ontario.
3. Chainage 558 + 00, C.N.R. relocation. Elevation 266 feet above sea level. Collector F. J. E. Wagner.
4. Chainage 542 + 00, C.N.R. relocation. Elevation 264 feet above sea level. Collector F. J. E. Wagner.

TABLE II

Species	Locality 2	3	4
Foraminifera			
Globulina sp.	x		
Elphidium bartletti Cushman			x
Elphidium orbiculare (Brady)	x		x
Cassidulina norcrossi Cushman	x		
Pelecypoda			
Yoldia arctica (Gray)			x
Macoma balthica (Linné)	x	x	x
Hiatella arctica (Linné)	x	x	x
Gastropoda			
Cylichna sp.	x		
Ostracoda			
? *Cypridopsis* sp.	x		
Cyprideis sorbyana (Jones)	x		

TABLE III

Species	Locality 2	3
Pelecypoda		
? *Anodonta grandis footiana* Lea		x
Anodontoides ferussacianus (Lea)		x
Pisidium abditum Haldeman	x	x
Pisidium cf. *P. vesiculare* Sterki	x	
Sphaerium cf. *S. striatinum* Lamarck	x	
Gastropoda		
Valvata sincera Say		x
Valvata tricarinata (Say) 101*	x	x
Valvata tricarinata (Say) 100	x	
Valvata tricarinata (Say) 000	x	x
Lymnaea stagnalis jugularis Say		x
Stagnicola cf. *S. palustris* (Müller)	x	
Helisoma anceps Menke	x	
Helisoma campanulata (Say)	x	x
Gyraulus parvus (Say)	x	x
Physa heterstropha Say	x	
Physa sp.		x

*The writer is here following the method proposed by La Rocque (1956) to designate the carinal variations of *Valvata tricarinata* (Say). The above designations refer to forms listed previously under the trinomial system as *Valvata tricarinata perconfusa* Walker, *V. t.* unicarinata de Kay, and *V. t.* simplex Gould. The "1" indicates the position of a developed carina and the "0" the position of a suppressed carina. Thus, 101 indicates that the superior and basal carinae are developed and the medial carina is suppressed.

and/or freshening of the waters during the waning stages of the Champlain Sea in this area. The freshwater species are shown in Table III. Most of the species are inhabitants of small lakes or ponds, but several species normally dwelling in quiet reaches of streams and creeks are intermingled. No change in conditions, such as stream to pond, or vice versa, is shown by the vertical distribution of the species. The shells are abundant throughout the jelly-like ooze, and occur to a much more limited extent in the lower part of the peat.

Although the marine-freshwater sequence is of considerable interest, of even greater interest is the presence of glochidia associated with the remains of one of the larger freshwater pelecypods. The specimen with the glochidia came from the lower 6 inches of the ooze at locality 3.

The small gastropods and pelecypods in the ooze, those that are less than ½ inch in length, are excellently preserved. Unfortunately, however, this is not true for the large nacreous pelecypods. They have been crushed and only the periostracum has been found adhering to the imprint of the shell in the ooze.

Examination of the remains of one of the large pelecypods under the microscope led to the discovery of the glochidia. The mass of larval forms occupies a position toward the ventral margin of the shell in the area slightly anterior to the umbos. They are extremely fragile and are therefore almost impossible to remove from the mass intact. Thus no count of them is possible, but an estimate would place the number at between four hundred and five hundred. Several specimens, freed from the mass and mounted in glycerine, were compared with figures in Surber (1912 and 1915) and Baker (1928). In size, shape, and character of the punctation of the valves, the glochidia agree with figures of those of *Anodontoides ferussacianus* (Lea). Length and height are equal, and have been measured at 0.33 mm. Figure 4*a* illustrates the surface ornamentation of the convex part of the valve, and Figure 4*b* shows the details of the marginal area more clearly. The outline of the

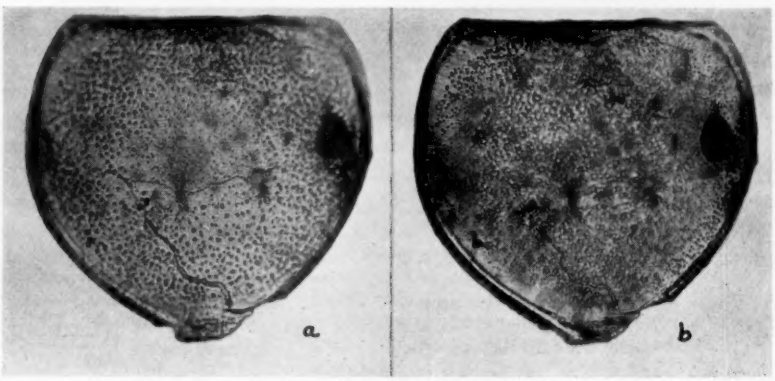

FIGURE 4.—Glochidium of *Anodontoides ferussacianus* (Lea) from peat bog northwest of Moulinette, Ontario. × 160. G.S.C. hypotype, no. 13, 595.

shell impression suggested *A. ferussacianus*, but without the glochidia no positive identification of the species could have been made.

This species lives at present in the Ottawa–St. Lawrence drainage area. There is one record of it as fossil from the district around Cornwall. Whittaker (in Keele and Cole, 1922) lists it from an alluvial deposit cut by a small creek in Lot 6, Con. VI, Charlottenburg Twp., north of Lancaster. This deposit post-dates the Champlain Sea, but is of sufficient antiquity that Whittaker considered the shells from it to the fossil.

Anodontoides ferussacianus is bradytictic, the glochidia being carried in the marsupium from August to May. Cause of death is, of course, unknown, but it may be that an especially severe winter killed this and the other specimens found at this same horizon.

No prior references to glochidia of such an age have been found in the literature.

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SECTION FOUR

Bute Inlet Wax

M. Y. WILLIAMS, F.R.S.C.

ABSTRACT

Large quantities of wax of jelly-like consistency form in Bute Inlet, B.C., and nearby waters, during winters of minimum temperature for the region. The wax disappears in the water as soon as the temperature rises.

The Pacific Fisheries Experimental Station has shown that the wax is of vegetable origin with a carbon 14 dating of zero ± 300 years.

This wax has not been reported from any other locality, and it is suggestive that this is the only place on the coast where Lodge Pole Pine (Pinus contorta) pollen occurs in large quantity on the water (in May and June).

BUTE Inlet is one of the larger fiords of the west coast of British Columbia and discharges into the complicated system of channels lying between the mainland and Vancouver Island at the north end of the Gulf of Georgia. Its crooked channel is about forty-eight miles long with an average width of about two and one-half miles. The channel profile is U-shaped. The upper two-fifths of its length varies in depth from 1,000 to 2,000 feet and the lower three-fifths from 2,000 to 2,200 feet. Only at its head is shallow water found. Here the Homathko and Southgate rivers deposit silt forming small deltas. These rivers head in rough mountainous country, the Homathko being fed by the great ice fields about Mount Waddington (13,000 feet). The copious spring and summer run-off from these rivers and from smaller lateral streams heading in the mountains and snow fields of the Coast Range provide a layer of fresh water twenty to thirty feet thick, which overlies the salt water of the inlet at the head mingling with salt water lower down. Streams of cold air also flow down the river valleys lowering the temperature below that of the coast in general. Bute Inlet has cut through the Coast Range batholith, consisting of quartz-diorite with inliers of schists and quartzites believed to be of Triassic age. The quartz-diorite is dated as late Jurassic to early Cretaceous in age.

During unusually cold winters masses of semi-consolidated, waxy material have been reported from Bute Inlet and from the mouth of Toba Inlet adjacent to it on the south, into which Bute Inlet water is probably carried by tides and currents. Such records are dated as follows: the winter of 1922; December, 1935; January, 1936; February, 1950; March, 1951; November 20, 1955; February 14, 1956, to March, 1956.

The attention of scientists was called to this peculiar wax in the winter of 1950 when "scow loads" of the material rolled up on the shores of Bute

Inlet, especially at Purcell Point, opposite Bear Bay, ten miles from the head of the inlet. Samples of the wax were sent to government and company offices, and the Pacific Fisheries Experimental Station, Vancouver, started an investigation under its director, Dr. Neal M. Carter, and his senior chemist, Dr. L. A. Swain. During 1951 the writer was in consultation regarding the geology of Bute Inlet, and visited the region three times in the naval research vessels *Cedarwood* and *Ehkoli*. The first visit, in February, 1951, occupied but one day. In May, the writer was guest scientist for two weeks with Dr. G. L. Pickard's oceanographic party, and in September he was in charge of the *Ehkoli* for one week, taking twenty-nine cores of the bottom at depths varying from 330 feet to 2,175 feet. These cores varied in length from small samples on hard bottom to thirty-five inches in mud. As shown by R. B. Toombs in "Some Characteristics of Bute Inlet Sediment," his paper read before this society in June, 1956, the bottom material is almost entirely of glacial origin and contains only small amounts of organic material.

The following chemical reports are quoted from Dr. Swain's manuscript.

The Bute Inlet wax consists of esters of fatty acids and fatty alcohols. It solidifies at about 11° C. Its specific gravity 20/20 is 0.8704. Its refractive index at 40° C is 1.4518. It yields 57% unsaponifiable matter (liquid) and 43% fatty acids (solid) and 0.75% glycerol.

Chromatographic analyses indicate the unsap was mostly fatty alcohols. It is therefore a liquid wax.

Iodine values "oil"	63.0
Unsap	78.4
Fatty acids	37.8

This wax is of vegetable origin and carbon 14 determinations give its age as 0 ± 300 years.

The nearest approach to Bute Inlet wax, according to Dr. Swain, is the seed wax of the plant *Simmondsia-chinensis* growing in southern California and Nevada. Dr. Swain consequently sought for possible plant material indigenous to Bute Inlet from which similar wax might be derived. No Tertiary basins are known in the vicinity and in any case the recent age of the wax limits its source material to the native flora. Sea-weeds and algae are absent and the lack of shallow water, the mixture of fresh and salt water, and the strong tidal and wind-currents limit the source material to land plants. As already stated, the Homathko and Southgate rivers are building small deltas and as logging is being carried on extensively in both valleys there is considerable bark and other waste carried into the inlet. This material in part floats out of the inlet and in part collects with the delta sediments, but neither in quantity nor character does it appear to be related to the wax.

Late in May, 1951, Dr. Pickard and the writer observed slicks several feet wide and 200 to 300 yards long of the pollen of Lodgepole pine (*Pinus*

contorta) floating on the inlet near its head. Local inhabitants reported that in June the inlet was covered with pollen. Samples collected near the west shore of Bear Bay, became separated into three layers: (1) a surface layer of yellow pollen, (2) an intermediate layer of brownish water, and (3) a bottom layer of debris. The layers were separated and "all three smelled disgustingly."

Each layer was shaken in a separating funnel with ethyl ether, each yielding a small quantity of oil. These oil samples all solidified in the refrigerator. Each contained unsaponifiable matter and fatty acids, as shown below in Table I. A small mountain stream enters Bear Bay near where these samples were taken but samples of its water were perfectly clear.

TABLE I

Layer	Wt. of oil G.	Percent unsap.	Percent fatty acids
1.	0.0555	8.6	81.4
2.	0.0352	11.4	77.3
3.	0.1204	19.0	61.511

The standard forestry survey of British Columbia by Mulholland estimates that 30,000,000 board feet of Lodgepole pine occur contiguous to Bute Inlet valley out of 67,000,000 board feet for the whole coastal region of the province. Knight Inlet to the north has 11,600,000 board feet, and Toba Inlet, closely adjoining Bute Inlet on the south, has only 600,000 board feet. Dr. Pickard left Bute Inlet with its increasing slicks of pollen late in May and sailed into Knight Inlet on May 27; no pollen was noticeable there.

An examination of Bute Inlet by the writer and inquiry from forest and logging company officials indicate that the stands of Lodgepole pine occur up the valleys of the Homathko and Southgate rivers and only in isolated patches on the upper slopes of the mountains bordering the inlet itself. In some seasons, pollen forms clouds over some inland valleys comparable to the smoke from forest fires. Mr. Orchard, the Chief Forester for British Columbia, reports that look-out stations have reported "fires" on the basis of pollen smoke-like masses. This pollen is mostly shed in late May and in June.

Since there was almost no available information on the chemistry of the pollen of the Lodgepole pine, on May 19, 1952, Dr. Swain collected pollen from the pine growing on Lulu Island, contiguous to Vancouver. The following information is from his manuscript report.

Branches bearing staminate cones, amounting to 11.3 lbs. yielded 336.5 g. of pollen on shaking them in the laboratory. This is a 6% yield.

Some of this pollen was extracted with acetone in a Soxhlet and the extract was extracted with light petroleum to yield a yellow solid amounting to 1.45% of the pollen. Composition and properties of this material are shown in the following table compared with similar data for Bute Inlet Wax.

	Pollen extract	*Bute Inlet Wax*
Wax m.p., °C	63	11
Iodine value	—	63.0
Unsap—%	47.5%	54.3%
State at 20°C	solid	liquid
Iodine value	—	78.4
Composition (Chromatographic analysis)		
Hydro-carbon	14.5%	5.5%
Fatty alcohols	72%	94%
Iodine value	11	—
Fatty acids	52.5%	—
State at 20°C	semi-solid	solid
Iodine value	70.8	37.8

Pollen stored 13 days in a beaker in the lab. turned mouldy and had a very yeasty smell. The light petroleum extract of the acetone extract amounted to 1.8% of the pollen as sampled (which was 6.9% of the heat-dried pollen). It was 49% unsap and 50% fatty acids, all three of these being solid at room temperature.

Pollen stirred in water at room temperature for 13 days first developed a yeasty smell and then changed to a vile odour, and yielded 22% of light petroleum extract (acetone extract). (This percentage is based on the weight of the heat-dried pollen—c.f. 6.9% above.) This extract was a solid consisting of 17.8% unsap and 73% fatty acids.

These results do not seem to be very promising either in the yield of solvent-soluble material nor in the properties of the solvent-soluble material that is there.

Dr. Swain's careful investigation is admittedly incomplete. The conditions prevailing at Bute Inlet are obviously entirely unlike those in the laboratory. The facts remain, however, that Bute Inlet wax and large quantities of Lodgepole pine pollen occur in Bute Inlet and not elsewhere on the coast. The pollen macerates into a waxy substance and the Bute Inlet wax is derived from a vegetable source. The resulting wax is present in the surface waters of Bute Inlet whenever extremely cold weather occurs and it then becomes semi-solid, collects into spherical masses, and drifts ashore. When the weather moderates the wax melts and returns to the water, but its presence has not been detected by chemical analyses. The mystery of the storage of this wax is as great as its origin, for the surface waters of the inlet are fresh, are flowing out of the mouth of the inlet and are being replaced by river water.

Right here is a suggestion worth exploring. The fresh water and the pollen come from the same regions—the valleys of the rivers. The large accumulations of wax in February, 1950, occurred under special wind conditions as well as at very low temperatures for the region. According to local inhabitants, the wind blew down the Homathko valley from the great ice fields to the northeast for about 10 days. The temperature dropped nearly to zero. Suddenly the wind turned to the south and only then did the slicks appear. Collecting around floating objects, balls of wax grew in the upper three feet of the surface water until some were eighteen inches in diameter, much of it rolling against the steep shores of the inlet.

There is a strong suggestion that the wax came down the river from the shores of back-waters and from muddy banks where it had been lodged in the early summer. (Several inches of macerated pollen are commonly reported as rolling upon the shores of lakes and rivers in the Lodgepole pine belts of Northern Canada.) From such resting places the wax may be dislodged by the violent winds and induced waves and currents of the Homathko and Southgate valleys. May it not be possible that the periodic occurrence of Bute Inlet wax depends upon the co-ordination of wind and temperature? Again, the accumulation of wax along the rivers may require several seasons after it has been depleted under conditions such as prevailed in February, 1950. The large masses of peat interspersed with log-jams in the lower reaches of the rivers form natural storage for pollen and its derivatives. Washed by the river currents these masses would, to a large extent, be free from the frost dominant farther up river and in tributary lakes. The peat beds extend at least nine miles up the Southgate River as seen by the writer; the conditions up Homathko River are not well known but reports suggest log-jams up it for a number of miles.

Conclusion

Bute Inlet wax, an ester of fatty acids and fatty alcohols, occurs in Bute Inlet, B.C. during spells of extremely cold weather or about six times in the last thirty-five years. It is recent in origin and is derived from plant remains. Local conditions preclude its origin from marine algae and the only known land plant material which occurs in the inlet in adequate quantity is the pollen of the Lodgepole pine (*Pinus contorta*). Like the wax, this pollen is almost confined on the British Columbia coast to Bute Inlet and connecting tidal waters. Bees have manufactured wax out of pollen for untold ages and pollen does macerate both in Bute Inlet and in the laboratory into waxy material.

Further research is required into the composition of the Bute Inlet wax and into the macerating and later changes taking place in pollen. The storage of wax in the valley of Bute Inlet during normal conditions requires much investigation. Meanwhile, unless some other source of the Bute Inlet wax can be found, something more than circumstantial evidence points to the pollen of Lodgepole pine.

So far as the writer has ascertained, this is the only known occurrence of wax such as that found in Bute Inlet. A solution of its origin, storage and occurrence may shed light on the origin of oil shales, such as the Huron shales of Lake Huron with their included *Sporangites huronensis*.

REFERENCE

Fisheries Research Board of Canada (1951). Bute Inlet Wax; Progress repts. of Pacific Coast Stations, no. 86, pp. 17–18.

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SECTION FOUR

Induced Radiation Analysis for Silicon, Aluminum and Sodium in Igneous Rocks

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ABSTRACT

Quantitative analysis of silicon, aluminum and sodium in rocks can be determined by the activation of these constituents with negligible interference from other elements. Samples weighing 300 grams of coarsely crushed rock exposed to fast neutrons for eight minutes give off gamma radiation proportional to the silicon content; and upon exposure to slow neutrons the same sample yields gamma radiation which is proportional to the aluminum content. This gamma radiation is measured in a scintillation counter. Rock samples of known composition are used as standards for comparison. Sodium can likewise be activated by longer periods of slow neutron bombardment.

Introduction

GAMMA radiation can be induced in a rock by the activation of the contained silicon, aluminum and sodium with negligible interference from other elements. Because this induced radiation is proportional to the mass of the respective element in the rock, it suggests a means of rapid quantitative analysis by comparing the gamma activity in a sample with that obtained from chemically analysed standards activated under the same conditions.

K. Bramadat constructed the earliest equipment and carried out preliminary experiments on a number of metallic and non-metallic elements and various rock types from the latter part of 1952 until the spring of 1954. R. A. Knutson developed the procedure for analysing for silica in 1953–4. A. C. Turnock applied this method to the analysis of aluminum and sodium during the academic session 1955–6.

The authors are indebted to Dr. R. W. Pringle and Dr. K. I. Roulston of the Department of Physics, University of Manitoba, for suggestions and guidance; to the McCullough Tool Company for contributions of neutron sources; to the Department of Geology, University of Minnesota, for providing analysed rock samples; and to the Geological Survey of Canada for financial support in this investigation.

Equipment

There are two distinct parts to the equipment used in activation analysis: (*a*) the neutron source for activating the rock sample, and (*b*) the scintillation counter for measuring the induced gamma radiation in the sample.

The Source

Neutron sources currently available consist of an intimate mixture of an alpha emitting material with metallic beryllium powder. The two types of mixtures that yield a high neutron flux are radium/beryllium and polonium/beryllium. The radium/beryllium source offers a constant neutron flux because of the long (1,600 year) half-life of the radium, but its strong gamma radiation is dangerous to personnel as well as a powerful field of interference for other measurements. Consequently, in all this work, the polonium/beryllium source, which has a neutron flux of 2,500 neutrons per second per millicurie of active material, was used exclusively. Polonium has a very small background of gamma radiation and this presents a much lower personnel hazard and instrument interference while at the same time permitting a stronger neutron source to be used. Polonium has one great disadvantage, however, in that it has a half-life of only 138.9 days and is thus a very costly source to maintain.

The sources used in these experiments varied all the way up to 10 curies. The neutrons emitted are polyenergetic having a range from 1 to 11 Mev but with an average neutron energy of 4.1 Mev. The sources come sealed in small metal capsules and were housed in a double cylindrical tank 4.5 feet in diameter and 3 feet high. The outer compartment of the tank was filled with a borax-water solution as an effective shield against neutrons, because borax has a high capture cross-section for slow neutrons; the inner tank 2.5×2 feet contained transformer oil as a thermalizing medium. A chlorine-free plastic cylinder 18 inches $\times$ 4 feet, closed at the lower end, projected down into the inner tank of oil to a depth of about 10 inches and the neutron source was normally stored at the bottom of this cylinder where it could be lifted out at will.

Slow neutrons. A neutron loses much of its energy by elastic collision with light nuclei. Since the mass of a neutron (1.00896 M.U.) and that of a proton (hydrogen nucleus 1.008128 M.U.) are so similar, the abundant hydrogen in the oil immediately surrounding the source has the effect of slowing down or "thermalizing" the neutrons. After about twenty or more collisions the neutron may approach thermal energy range, that is, less than 0.5 electron volt. In order to enclose completely the neutron source with hydrogenous material, a disc of paraffin was placed above the source in the cylinder and experiments demonstrated that a paraffin thickness of 5.75 inches gave optimum results for slow neutron bombardment with a 5 curie source. A sample of crushed rock could then be lowered into the cylinder to rest upon the paraffin disc and in such a position would be within the zone of slow neutron activation.

Fast neutrons. The source could readily be lifted out of the tank by a pulley and track system and set down on a pedestal in an open space removed from any hydrogenous material. The container holding a crushed rock sample could then be placed directly over the source and thus be activated by "fast" neutrons.

Scintillation Counter

A scintillation counter was used for measuring the gamma radiation. Components of this apparatus are:

(*a*) *Sorenson voltage regulator*, model 2000 SAC, which supplied 115 volt AC current with less than 1 per cent variation.

(*b*) *Power supply*, Lambda model 28, for regulated voltages in D.C. for the circuits and A.C. for the heater filaments in some tubes.

(*c*) *The scintillator*, a crystal of sodium iodide thallium activated. This was a cylinder 2 × 2 inches with a magnesium oxide reflector within an aluminum case.

(*d*) *Photomultiplier*, a DuMont 3 inch tube optically coupled to the crystal. Each scintillation or light flash in the crystal produces a photoelectric effect on the cathode of the tube yielding electrons which are focused onto a series of dynodes that multiply the number of electrons so that an enlarged current pulse emerges from the tube.

(*e*) *A cathode follower*, to pick up the pulses from the photomultiplier tube and send them to the amplifier.

(*f*) *The amplifier*, to effect a linear amplification up to a maximum output of about 80 volts.

(*g*) *A discriminator*, to enable the operator to count only those pulses of desired amplitude. When it is operated as an "integral discriminator" all pulses higher than the setting of the "trigger level" are counted. However, when it is operated as a "differential discriminator," there is imposed an upper limit to the pulses which are counted; the distance or energy range between the upper and lower limits of the pulse heights is designated the "window." Because the window analyses the energy of the pulses it may be called an "analyser" as well as a "differential discriminator."

(*h*) *A glow counter*, Atomic Instrument Company, Model 162, to record the number of gamma rays entering the crystal over any measured interval of time.

(*i*) *Tektronix oscilloscope*, Type 511-AD, an auxiliary piece of equipment useful in pulse analysis and in locating any source of trouble in the apparatus.

Principles

Most elements present in igneous rocks become activated and give off some form of induced radiation when a sample is subjected to neutron bombardment. However, only silicon, aluminum, and sodium emit gamma rays which are sufficiently prominent and have an appropriate half-life to enable them to be distinguished and counted under the conditions of the experiments. Fast neutrons are used to activate silicon, whereas slow (thermal) neutrons activate both aluminum and sodium to give the desired effects. The reactions expected when an igneous rock is bombarded by polyenergetic neutrons are shown in Table I for thermal neutron activation, and Table II for fast neutron activation for the induced gamma radiation

TABLE I

NUCLEAR DATA FOR THERMAL NEUTRON/GAMMA ACTIVATION

Element	Target nucleus	Abundance per cent	Cross-section millibarns	Isotope produced	Half-life	Energy ray Mev
Si	Si^{30}	3.05	120	Si^{31}	2.7 H	0.0
Al	Al^{27}	100.	212	Al^{28}	2.27 M	1.78
Fe	Fe^{54}	5.84	—	Fe^{55}	2.9 Y	—
	Fe^{56}	91.66				
	Fe^{57}	2.17				
	Fe^{58}	0.33	801	Fe^{59}	47 D	1.1, 1.3
Mg	Mg^{24}	78.60				
	Mg^{25}	10.11				
	Mg^{26}	11.29	50	Mg^{27}	9.5 M	0.84
						1.01
Ca	Ca^{40}	97				
	Ca^{44}	2.13	600	Ca^{45}	152 D	—
Na	Na^{23}	100	600	Na^{24}	14.9 H	1.37
						2.758
K	K^{39}	93.2				
	K^{40}	0.012				
	K^{41}	6.8	1,000	K^{42}	12.4 H	1.51
Mn	Mn^{55}	100	13,000	Mn^{56}	2.59 H	2.13
						1.81
						0.845
P	P^{31}	100	200	P	14.3 D	—

TABLE II

NUCLEAR DATA FOR FAST NEUTRON/GAMMA ACTIVATION

Element	Target nucleus	Abundance per cent	Cross-section millibarns	Isotope produced	Half-life	Energy ray Mev
Si	Si^{28}	92.27	3.	Al^{28}	2.27 M	1.78
	Si^{29}	4.68	2.7	Al^{29}	6.7 M	1.2, 2.3
	Si^{30}	3.05				
Al	Al^{27}	100	52.4	Mg^{27}	9.45 M	0.84, 1.85
	Al^{27}	100				
Mg	Mg^{24}	78.6	191.	Na^{24}	15 H	1.37
						2.75
	Mg^{25}	10.11	44.9	Na^{25}		
	Mg^{26}	11.29				
K	K^{39}	93.44	10.	K^{38}	7.7	2.16
	K^{40}	0.012				
	K^{41}	6.55	2.9	K^{42}	12.4 H	1.5
Mn	Mn^{55}	100.0	3.5	Mn^{56}	2.59 H	1.51
Ba	Ba^{138}	7.66	2.6	B^{139}	85 M	1.65

only. The list does not include oxygen or carbon as their most abundant isotopes are transformed to other stable isotopes by neutron bombardment at the energy level of the sources used. The neutron capture cross-section is expressed in "barns" (1 barn equals 10^{-24} cm^2), and this expresses the probability of interaction between the bombarding particle and the target nuclei by giving the effective target area. The reactions for Al^{27} and Si^{28}, Si^{29}, and Si^{30} for fast and thermal neutrons are:

(1)	Al^{27}—100%	(th n, γ)	2.3 minutes Al^{28}	212. millibarns
(2)	Al^{27}—100%	(1 Mev n, γ)	2.3 minutes Al^{28}	.41 millibarns
(3)	Al^{27}—100%	(1 Mev n, p)	9.45 minutes Mg^{27}	2.80 millibarns
(4)	Al^{27}—100%	(1 Mev n, α)	14.9 hours Na^{24}	0.60 millibarns
(5)	Si^{28}— 92.27%	(1 Mev n, p)	2.3 minutes Al^{28}	3.0 millibarns
(6)	Si^{29}— 4.68%	(1 Mev n, p)	6.7 minutes Al^{29}	2.7 millibarns
(7)	Si^{30}— 3.05%	(th n, γ)	2.7 hours Si^{31}	120. millibarns
(8)	Si^{30}— 3.05%	(1 Mev n, γ)	2.7 hours Si^{31}	1.1 millibarns

Correction of Al Analysis for Minor Si Activation

Reactions (1) and (7) show that aluminum and silicon have only one reaction with thermal neutrons. The half-life of Si^{31} is sufficiently long to provide a means of differentiating between these two elements in an activated sample. But experimentally it was found impossible to thermalize all neutrons emitted from the source because some of the fast neutrons reflected from the surrounding oil would be only partially thermalized thus causing reaction (5) to take place. This gives a small but significant reaction from the silicon during the thermal activation for an aluminum analysis, making it necessary to analyse for silicon first and subtract this from the total.

Correction of Si Analysis for Minor Al Activation

Reactions (2) and (5) show that Al^{27} and Si^{28} both produce Al^{28} when bombarded with fast neutrons. The cross-section for Al^{27} in reaction (2) is only .41 millibarns whereas that for Si^{28} is 3.0 millibarns or 7.5 times larger. In a granite having 15 per cent Al_2O_3 and 70 per cent SiO_2, the relative abundance of Al^{27} and Si^{28} is 7.95 and 30.1 per cent respectively. Thus the Si^{28} isotope being 3.8 times more abundant by weight or 3.66 by numbers of atoms and having a 7.5 times greater cross-section gives an induced radiation approximately 27.5 times greater than that from the contained Al^{28}.

The equivalent of the contained Al^{28} must be deducted from the total induced radiation in order to obtain that due only to Si^{28}. Fortunately, the alumina content of igneous rocks is fairly constant, varying just a few per cent from acid to basic types, so the amount to be subtracted varies only slightly. Therefore, if a chemically analysed standard of similar type to the

unknown is used, such as a granite standard with an acid rock sample or a gabbro standard with an unknown basic rock, the error introduced into the silica analysis would be due only to the variation in alumina from the norm, and this error for Al^{27} with its very small cross-section for fast neutrons is so slight as to be well within the limits of statistical error. Assuming an error of 2 per cent in the Al_2O_3 content, this would introduce a variation in the final SiO_2 analysis of ± 0.5 per cent.

Eight analysed samples of igneous rocks for use as standards were obtained from the Rock Analyses Laboratory, University of Minnesota. They covered the range from very acid granite (77.75 per cent SiO_2) to very basic gabbro (38.91 per cent SiO_2). The standard used for silica was Black Island silica sand containing 99.33 per cent SiO_2.

Sample Preparation

All samples analysed should have the same geometry relative to the neutron source and to the crystal of the detector. Cylindrical sample containers were made of clear plastic with a central cavity so the sample was distributed evenly over the top and around the side of the crystal. The plastic must be a variety free from chlorine since Cl^{35} has an appreciable cross-section for thermal neutrons. These containers held 300 grams of granite crushed to minus ¼ inch, though in the case of basic rocks of higher specific gravity slightly heavier samples were required to obtain equal volume and therefore uniform geometry. Fine grinding is undesirable. Since the strength of the induced radiation is directly proportional to the content of the activated elements, one can simply use a larger sample if the element under consideration is present in a low concentration. However, self absorption is a factor which enters as the bulk of the sample increases, hence uniformity of size was maintained.

Since the half-life of polonium is only 138.9 days, the strength of the neutron flux changed daily. This change was corrected for by determining a standard silica sand sample with each series of measurements. For greater accuracy this should be checked against the decay curve.

Calibration of the discriminators was accomplished by placing a Cs^{137} source over the crystal in the scintillation counter and plotting a differential curve. Cesium has only one gamma ray at 0.662 Mev and the photo-electric peak occurs at a certain dial setting, say 24 volts. A Co^{60} source has two peaks at 1.17 and 1.33 Mev and this source may also be used to calibrate the dial of the instrument in terms of energy.

The Cs^{137} source was also used to check the stability of the counter. Immediately before and after recording the induced radiation in a sample, a 30 second check count was made with the source placed in a standard position. If the difference between the two readings was more than 2 per cent, the results were discarded.

Silica Sand Analysis

Fast Neutrons

(1) A 300 gram sample of silica sand used as one of the standards was weighed and loaded into the sample holder.

(2) The neutron source was then removed from the tank and placed in the open upon a pedestal. The sample was placed over it (Figure 1) for six minutes of irradiation with fast neutrons and then quickly transferred to the crystal in the counter, the lead castle lid closed and high voltage to the

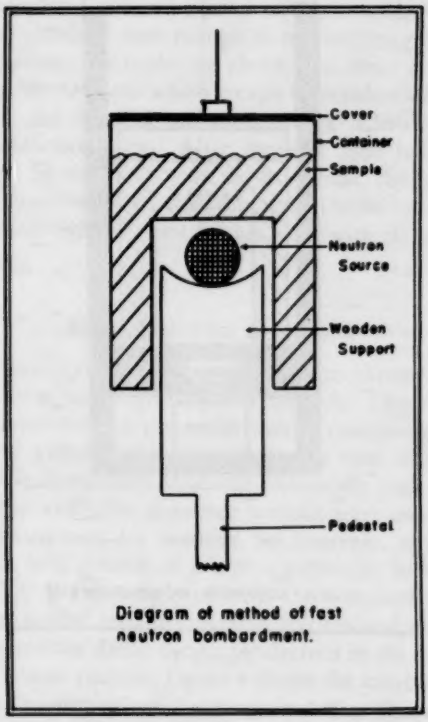

Figure 1

photomultiplier tube switched on. Also, the neutron source was returned to the tank. A fifteen second time lag was allowed for these manipulations and stop-watch control is necessary. The moment the sample is lifted away from the source is the point of initial activity or "zero" point on the decay graph. The time graphs showing the decay curves of the isotopes formed by irradiation were interpolated to correct for this time lag and thus the initial activity, at time zero was obtained.

(3) All gamma rays above 300 Kev were counted and cumulative counts were taken every 30 seconds for the first six minutes and then every minute for the remainder of the decay period. The counts per 30 seconds were plotted as the ordinate against time on semi-logarithmic graph paper. The counting rate for any specific time is taken as the difference between the reading at that time and the one immediately preceding.

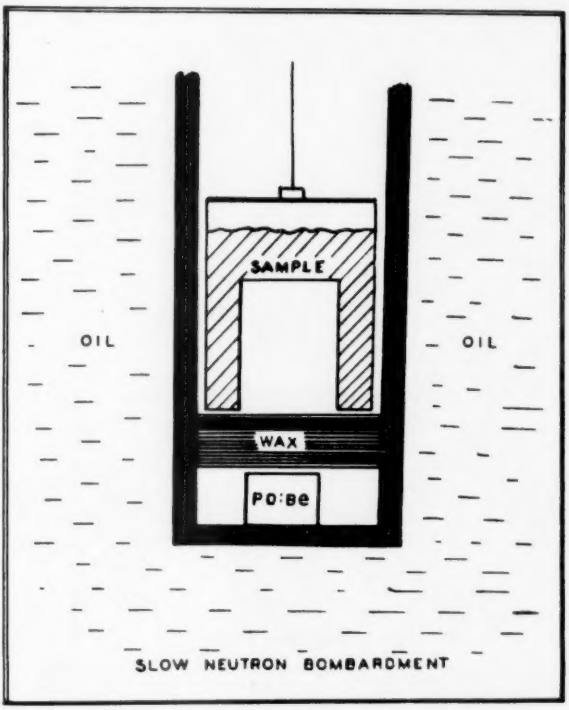

FIGURE 2

(4) The decay curve B for this silica sand as plotted on semi-log. paper (see Figure 3) dips steeply and then flattens out into a nearly horizontal tail. The longer-lived isotopes and the background count are in this tail which is extrapolated back to zero. By subtracting the counts in this background curve from the decay curve one obtains the straight line component having the 2.3 minute half-life. The initial activity of this 2.3 minute component is proportional to the Si content.

Photographs of the spectrum from the activated silica sand were obtained with the cathode ray oscilloscope, but are difficult to reproduce here. The spectrum exhibited a distinct line at 1.8 Mev which is the energy level of the Al^{28} gamma ray. Despite the low cross-section (3.0 millibarns) of Si^{28} for

fast neutrons, a relatively high initial activity of 1,460 counts per 30 seconds or 4.9 counts per 30 seconds per gram of silica was obtained for the prevailing neutron flux.

Silica Sand

Slow Neutrons

The same sample of silica was irradiated with slow neutrons: the source was left in the tank and the disc of paraffin placed above it. The sample was then placed on top of the paraffin (Figure 2), left for the six minute irradiation period then lifted out and placed on the counter. The decay curve A in Figure 3 was obtained even though Si has no gamma intensity due to thermal neutron activity. As explained above, this effect is undoubtedly due to the presence of fast neutrons which escape thermalization.

The increase in the induced radiation during activation is the mirror image of the radioactive decay. After three or four half-lives the curve becomes quite flat. In the early work by Bramadat, the irradiation period used was only 4.5 minutes, but this was increased to six minutes by Knutson for Si. Turnock used eight minutes for his work with Al and sixteen hours for the Na analysis.

Rock Analysis for Silica

A series of accurately analysed igneous rocks was obtained from the Rock Analysis Laboratory at the University of Minnesota. This series covered the range of compositions from a very acid granite containing 77.75 per cent silica to very basic gabbro with only 38.91 per cent silica. These rocks, together with the analysed silica sand and chemically pure alumina, served as standards against which the unknown samples were compared.

Given an unknown rock for analysis, for example, a visual inspection shows that it is an acid granite of a type comparable to standard granite No. R-1883. A 300 gram sample of both the standard granite and the unknown rock are loaded into two sample holders and each is irradiated with fast neutrons and the decay curves are derived in the manner described above for the silica sand analysis. Figure 4 shows the curve for this standard granite which for the strength of the neutron source then prevailing gives an initial induced activity of 1,150 counts per 30 seconds. Since this standard granite contained 77.75 per cent or 233.25 grams of silica in the 300 gram sample, the initial activity is 1,150/233.25 or 4.93 counts per 30 seconds per gram of contained silica.

The unknown granite sample is then irradiated while the neutron source is at the same strength and its initial activity derived in the same manner. Assuming an initial activity of 1,042 counts per 30 seconds, then the contained silica is $1{,}042/4.93 = 211.3$ grams or 70.43 per cent. While the activation is due to the Si only and not SiO_2, the ratios for SiO_2 are equivalent and more convenient to use. The results of the measurements

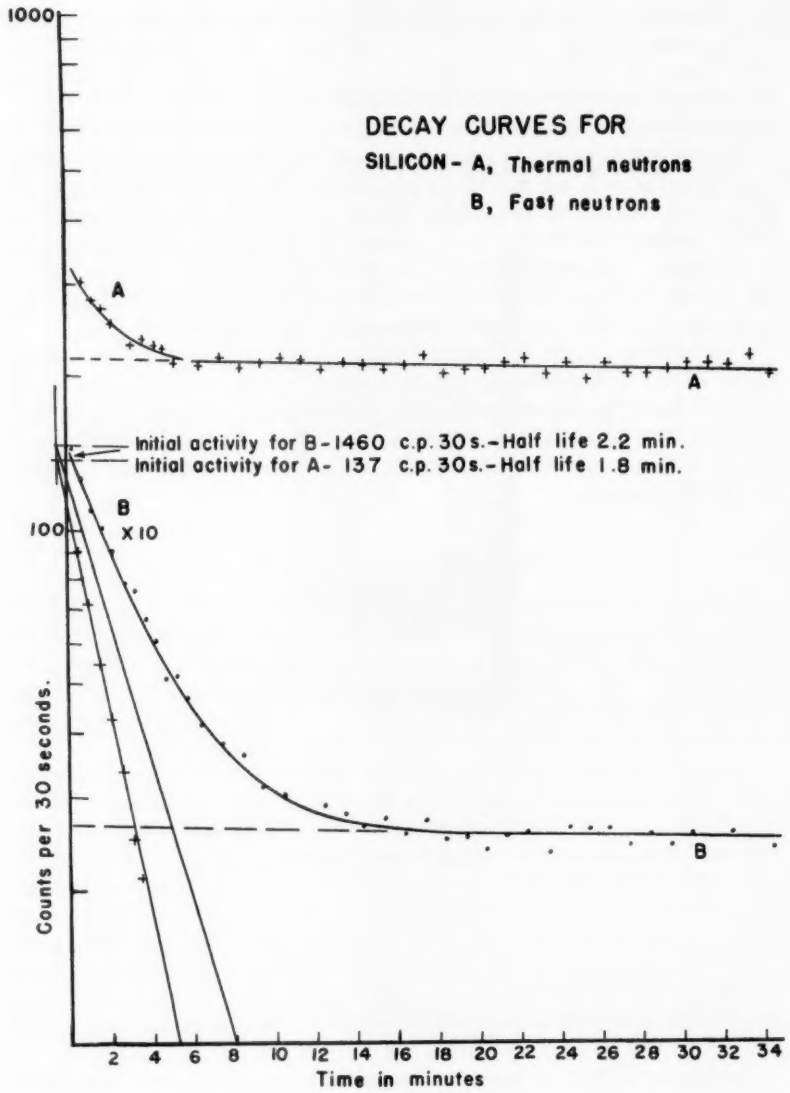
DECAY CURVES FOR
SILICON - A, Thermal neutrons
B, Fast neutrons
1000
100
A
A
Initial activity for B - 1460 c.p. 30 s. - Half life 2.2 min.
Initial activity for A - 137 c.p. 30 s. - Half life 1.8 min.
B
X 10
B
Counts per 30 seconds.
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34
Time in minutes

FIGURE 3

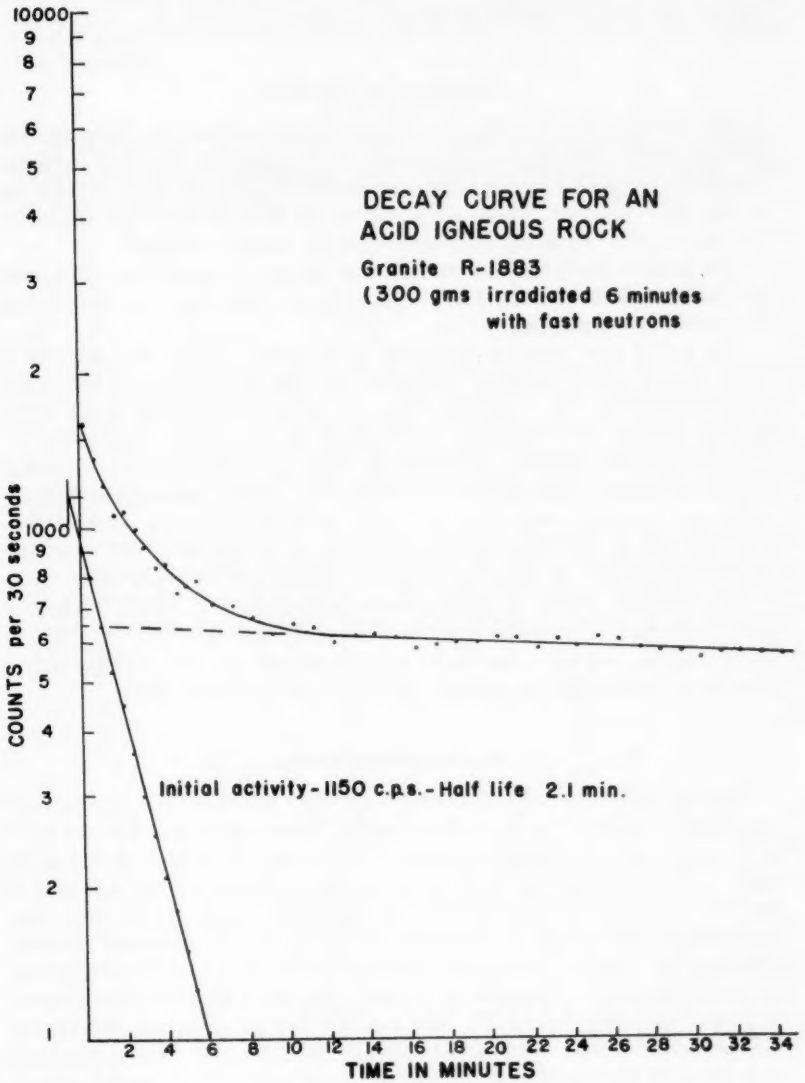
DECAY CURVE FOR AN
ACID IGNEOUS ROCK
Granite R-1883
(300 gms irradiated 6 minutes
with fast neutrons
COUNTS per 30 seconds
10000
9
8
7
6
5
4
3
2
1000
9
8
7
6
5
4
3
2
1
Initial activity - 1150 c.p.s. - Half life 2.1 min.
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34
TIME IN MINUTES

FIGURE 4

obtained on the series of analysed rock samples indicates that the silica content should be reported as 70.43 ± 1.8 per cent SiO_2.

Analysis for Alumina

The analysis for the alumina content should follow the silica analysis without delay while the neutron source is at essentially the same strength. This is accomplished by the same manipulations except that the irradiation is with slow neutrons. Three decay curves for slow neutrons are required: (*a*) silica sand, (*b*) standard granite, and (*c*) unknown sample.

The initial activity for slow neutrons as shown in Figure 3 is 137 counts per 30 seconds for the 99.33 per cent SiO_2, or 1.38 counts per 30 seconds for each 1 per cent silica.

The initial slow neutron activation of standard granite No. R-1883 is 2,560 counts per 30 seconds. Subtract from this the 77.75 × 1.38 (107) counts due to the 77.75 per cent SiO_2 which leaves 2,453 from the 12.71 per cent Al_2O_3 or 193 counts per 30 seconds for each 1 per cent Al_2O_3.

The initial slow neutron activation curve for the unknown gives an initial activity of 3,035 counts per second. Since it has already been shown to have 70.43 per cent SiO_2 then 70.4 × 1.38 or 97 counts must be subtracted to give 298 due to Al. Since the activation constant for Al is 193, then the Al_2O_3 content for the unknown rock is 2,934/193 = 15.2 per cent.

The induced activity of aluminum in an igneous rock, when compared with a standard of a similar type, and allowing ±2.5 per cent error in the silica analysis, will have a probable error within 6 per cent, and the above content may therefore be reported as 15.2 ± 0.9 per cent Al_2O_3.

Analysis for Sodium

Natural sodium has only the one isotope Na^{23} which is activated by slow neutrons to yield Na^{24} with a half-life of 14.9 hours and which has two hard and equally abundant gamma rays at 1.38 Mev and 2.76 Mev. A 300 gram rock sample was prepared in the usual manner but before being activated it was placed in the counter and the natural radioactivity of the rock plus background determined at the same setting of the discriminator as used following irradiation. The sample was then placed in the tank overnight for a 16 hour period of bombardment by slow neutrons. Other elements become activated including Si, Al, Fe, Mn and K^{41} but by using the differential discriminator with the window set to count the 2.63–2.81 Mev range, then only the 2.76 Mev photopeak of the Na^{24} is counted and the initial activity may be taken directly as the 10 minute count, less background, made immediately upon removing the sample from the source. This count is directly proportional to the sodium content and may be used to determine the content of this element by comparison with a known sodium standard of like weight that was subjected to corresponding irradiation. The degree of

accuracy of the sodium by this method, as determined experimentally, is 15 per cent and may therefore be given ±0.3 per cent in the reported Na_2O content.

Conclusions

Results obtained on the irradiation of a series of analysed rock samples show that activation analysis for silica, alumina and sodium is feasible with probable errors as follows:

	Relative	*Absolute*
SiO_2	± 2.5%	70.0±1.75%
Al_2O_3	± 6.0%	15.0±0.9%
Na_2O	±15%	2.0±0.3%

While these are not as precise as a good chemical analysis, they are within a range of accuracy acceptable for many purposes. One operator recording manually can make nine SiO_2 or Al_2O_3 determinations in a day, though this number would be increased if an automatic recorder were used. Sodium analyses are even less time-consuming, requiring under forty-five minutes of labour.

Unfortunately, the cost of polonium/beryllium sources is prohibitive for most activation analysis, but radium/beryllium sources can be obtained on a less costly rental basis. Also, neutron generators will be available in the near future which should greatly facilitate the useful application of this method of analysis.

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SECTION FOUR

Biogeochemical Prospecting for Cobalt

HARRY V. WARREN, F.R.S.C., and ROBERT E. DELAVAULT

ABSTRACT

The cobalt content of trees and shrubs growing above cobalt ore is high enough to be estimated by a relatively simple laboratory method on samples one gram in weight.

Most positive samples contain from one to three p.p.m. of cobalt in dry plant and from fifty to three hundred in ash. This appears to be from ten to one hundred times the amount encountered in vegetation from non-mineralized areas.

Introduction

ALTHOUGH cobalt is known to be essential to the well being of some animals, it has not yet been proved to be a vital constituent of any plants. Nevertheless, vegetation exhibits a wide range in its cobalt content which depends on many factors, including the presence or absence of obvious cobalt mineralization, and the degree of weathering of the underlying ore, soil, or rock minerals.

Cobaltian biogeochemistry may be of value in the search both for buried mineralization valuable for its cobalt content and for other deposits, such as silver, in which the cobalt is significant only as a pathfinder element.

The authors have yet to discover any vegetation in which there is no cobalt, but variations commonly ranging from five to one hundred times background have been encountered near important mineralization. Because the amounts of cobalt involved are different from those involved in problems of animal nutrition, and because high precision is not normally vital in attempting to find buried ore deposits, it has been found practical and convenient to use a simpler analytical method than any commonly employed in determining the cobalt content of plants.

Analytical Method

The cobalt reagent used is beta nitroso-alpha naphtol or (2—nitroso—1 naphtol) which is an isomer of the usual reagent for cobalt, nitroso-beta naphtol. Beta nitroso-alpha naphtol is less efficient than its better known isomer and, in particular, will not react with iron at pH 10. At such high alkalinity extremely small amounts of cobalt are not recovered satisfactorily, but one headache is avoided, namely, interference by other and more abundant metals. The beta nitroso-alpha naphtol is used in a 1 per cent solution

in acetone: all other reagents are solutions of chemically pure compounds, which normally do not contain enough cobalt to vitiate results in distilled or effectively demineralized water.

Cobalt precipitate is gathered by shaking with toluene. If the cobalt reagent has been oxidized to a nitro compound the toluene will be coloured yellow. Old solutions of nitroso-naphtol should be tested before use by running a blank. Hydroxylamine may be added for protection, particularly against oxidation where large amounts of manganese are present.

Procedure

Ash one gram of twig at a dull red heat of about 1,100°F. Dissolve the resulting ash in 1 to 2 ml. of hydrochloric acid (equal volumes of concentrated acid and water). Evaporate this solution to dryness in 15 to 30 minutes and take up the residue with two drops of 1:1 hydrochloric acid and a few ml. of water. Pass this solution into a 15 × 125 mm. test tube made of pyrex or similar hard glass, and add 1 ml. of 10 per cent Rochelle salt, 4 drops of 20 per cent hydroxylamine hydrochloride, and 8 drops of ammonia: this ammonia is made up of concentrated ammonia diluted with its own volume of water. Mix this solution and then add 1 drop of 1 per cent beta nitroso-alpha naphtol in acetone, mix and add 10 drops of toluene, which make close to ¼ ml. of toluene. Close with a cork stopper, turn upside down and shake for 15 seconds, or about 70 strokes. Place upright and after a few minutes compare the supernatant toluene with that of standards containing 0.2 to 4 micrograms of cobalt. The standards should be prepared in exactly the same way except that two drops less of ammonia may be used because there is practically no acid to neutralize. Below 1 microgram cobalt recovery is imperfect and the colour of standards must be expected to be much paler than would be the case were they obtained by correctly diluting a stronger toluene extract.

Results of Investigations

Our results, which are presented in as condensed a form as possible, are given in Tables I and II.

Most of the analyses were made on five gram samples of young stems comprising the most recent three years' growth. Young stems usually accumulate trace elements satisfactorily, particularly if ash, rather than dry plant content, is being considered. Comparable results might be obtainable using two grams of leaves or needles, but we have found it preferable to use young stems which, because they are likely to be lower in silica, are less likely to cause additional analytical difficulties.

All the numbers express parts per million (p.p.m.) of cobalt, the first figure being in oven dried plant material, and the second, in brackets, in ash.

TABLE I

POSITIVE SERIES

(Samples from vicinity of veins containing cobalt. All samples, except "Windpass, B.C.," from Cobalt, Ontario)

Sample stations	K.C.T.	K.C.U.	K.C.V.	K.C.W.	K.C.X.	Windpass, B.C.
Balsam (*Abies balsamea*)	3.5(150)	1.3(42)	1.0(27)	0.9(33)	2.5(68)	1.5(63)[a]
Jackpine (*Pinus Banksiana*)					1.0(22)	1.5(88)[b]
Whitepine (*Pinus strobus*)	3.7(250)					
Black Spruce (*Picea mariana*)	6.0(330)	3.8(210)				
White Spruce (*Picea glauca*)			0.8(28)	1.5(65)	1.3(90)	
Tamarack (*Larix laricina*)					0.7(40)	
Cedar (*Thuya occidentalis*)	1.2(35)	1.8(55)			1.0(30)	
Birch (*Betula papyrifera*)	3.0(120)	3.7(170)	1.2(75)	1.3(60)	10.0(360)	
Alder (*Alnus* sp.)		1.5(55)	1.0(37)			
Willow (*Salix* sp.)	2.5(95)	1.2(45)	1.3(30)	1.4(74)	0.8(36)	
Maple (*Acer* sp.)	0.3(14)	0.8(20)	0.4(17)	0.7(32)	1.0(34)	
Poplar (*Populus tremuloides*)	0.8(13)	0.9(24)	0.6(15)	1.0(18)	1.6(50)	
Pin Cherry (*Prunus pennsylvanica*)	1.2(17)	0.6(20)	0.7(15)		0.7(16)	
Blueberry (*Vaccinium* sp.)	2.5(160)	3.5(320)	0.8(90)	0.8(57)	0.8(73)	

[a] *Abies lasiocarpa* or Mountain Balsam. [b] *Pinus contorta* or Lodgepole Pine.

TABLE II

NEGATIVE SERIES

(Samples from areas in which no cobalt mineralization was known in the vicinity. All samples except "Windpass, B.C." from Ontario and Quebec areas, where climate roughly equivalent to areas where positive series collected)

	Anorthosite	Glacial drift	Rhyolite	Muskeg and clay	Selections from suites near weak zinc mineralization	Remote from mineralization Windpass, B.C.[a]
Balsam		0.10(3)	0.6(23)	0.3(11)	0.15(3)	0.3(12)[a]
Jackpine			0.08(6)		0.1(7)	0.25(13)[b]
Black Spruce	0.15(10)	0.15(3)	0.7(49)	0.3(18)	0.3(12)	
Tamarack	0.06(3)				0.15(10)	
Cedar					0.1(4)	
Birch	0.03(2)		0.25(14)	0.24(10)		
Alder		0.1(6)	0.25(13)	0.06(3)		
Willow	0.2(5)			0.08(3)	0.35(12)	
Maple					0.08(3)	
Poplar		0.1(10)	0.18(5)	0.3(13)	0.30(8)	
Pin Cherry				0.02(1)		
Blueberry	0.07(4)			0.15(3)	0.75(35)	
Labrador Tea *Ledum groenlandicum*	0.04(3)		0.3(25)	0.75(21)		

[a] *Abies lasiocarpa* or Mountain Balsam [b] *Pinus contorta* or Lodgepole Pine.

Discussion

The contrast between positive and negative suites is too obvious to need much comment. Some species of trees exhibit a greater ability to concentrate cobalt than others: spruce and birch tend to have higher cobalt contents than cedar and maple even where they are all growing in close association.

As might be expected, biogeochemical studies in specific projects may not always produce results as easily interpreted as the above tables might suggest. A suite taken from an area in western Ontario where strong mineralization is devoid of any evidence of cobalt provided the results given below:

Tamarack	.25(19)
Willow	.50(27)
Poplar	1.20(28)
Pin Cherry	.50(13)

These figures indicate the possibility that some types of mineralization are associated with enough cobalt to enable this element to be used either as a pathfinder or to corroborate the presence of unusual concentrations of trace elements in vegetation in an area where mineralization is suspected.

Cobalt Content of Different Organs

In Table III the results are given of analyses obtained from the various component parts of some specimens from the suite designated K.C.X. in Table I. It can be seen that cobalt is distributed quite evenly in the younger

TABLE III

Species	Stems			Needles		
	Youngest growth	Second year growth	Third year growth	Latest season	Two year old	Three year old
Balsam	1.(22)	2.5(68)	1.6(56)	0.8(9)	1.5(35)	1.1(25)
White Pine	1.6(80)	1.0(26)	1.0(42)	0.5(20)	1.5(55)	
White Spruce	1.2(36)	2.5(92)	0.6(28)	Mixed	1.2(31)	
Willow	1.0(32)	0.7(25)	0.5(15)			
Maple	0.8(19)	Combined	0.5(15)			
Poplar	0.9(19)	0.9(20)	0.6(12)			
Pin Cherry	0.6(11)	0.6(9)	0.5(10)			

parts of a bough. Thus, in general practice, it is quite permissible to select stems which represent the growth of the last three years of any tree whose cobalt content is being investigated. In some areas of Canada vegetal growth is comparatively slow, and only by taking three years' rather than one year's growth can biogeochemical sampling be made tolerably efficient. Fortunately, in the case of cobalt, in contrast to copper and zinc, it is possible to

determine anomalous vegetation using any young part of a tree or lesser plant.

A number of analyses of leaves and needles have confirmed the impression given by Table III, namely, that they are usually poorer than boughs in trace metals when determined as p.p.m. of dry plant and especially when reported as p.p.m. of ash.

The amount of cobalt reported in all the above tables is very low compared with what may be expected in vegetation growing above lateritic soils containing significant amounts of cobalt. Mr. C. Miller has encountered vegetation with much higher cobalt contents[1] but the lateritic conditions with which he was dealing are not likely to be found in Canada.

Conclusions

There are sufficient variations between the cobalt contents of trees and lesser plants growing close to cobalt mineralization and those removed from such mineralization to enable biogeochemistry to be used as a prospecting tool. There is some evidence to suggest that more than normal amounts of cobalt may be associated with some favourable mineral-bearing formations and that it may be possible to use biogeochemistry to search for these favourable formations.

Acknowledgments

This work has been made possible by funds supplied by the Defence Research Board of Canada (Grant No. D.R.B. 7510-06), the Geological Survey of Canada, and the Consolidated Mining and Smelting Company (Canada) Limited, and by generous co-operation from other mining companies, notably Kennco Explorations (Canada) Limited, and Dominion Gulf Company. Dr. A. E. Smith collected the "Windpass" samples, and to him the authors also acknowledge their indebtedness.

[1]Personal communication.

TRANSACTIONS OF THE ROYAL SOCIETY OF CANADA
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SECTION FOUR

Third Annual Report of the Committee on Precambrian and Related Dating

R. M. FARQUHAR
Presented by J. B. MAWDSLEY, F.R.S.C.

REMARKABLE progress in the field of absolute age determinations has been made in the past year, both in defining the reliability of absolute ages and in producing them in sufficient quantity to be of service to geologists. Five years ago only Precambrian minerals containing macroscopic quantities of uranium and thorium could be dated with any accuracy. Now the uranium-lead, potassium-argon and rubidium-strontium methods all appear capable of providing trustworthy age determinations (with certain predictable exceptions), and ages may be obtained using small samples of the common rock-forming minerals, and, under certain conditions, for sedimentary rocks as well. The age of the youngest samples which it is possible to date borders on the pleistocene. The only remaining barrier to the subdivision and correlation of widely separated areas is the lack of facilities with which to sample and date the rocks.

The basic research on methods of age determination has apparently settled, although not in a completely satisfactory manner, the problem of the half-life of the decay of rubidium-87. The value of this half-life is that which gives the best agreement between rubidium-strontium ages and uranium-thorium-lead ages determined on the same mineral samples (Aldrich *et al.*, 1956). It has long been felt that the rubidium-strontium method would be seriously limited by the small amount of rubidium in common rock-forming minerals. The sensitivity of modern mass spectrometers overcomes this difficulty so that the amounts of rubidium and strontium in small samples of common minerals can be determined accurately. It has also been found that rubidium-strontium ages determined for different minerals from the same rock are in agreement, a criterion of dependability which is often lacking in some of the other methods of age determination.

The usefulness of the potassium-argon method of age determination is still hampered by the problem of argon loss from feldspars. Trustworthy age determinations may be made on micas, and it is in this field that the largest body of useful data has accumulated.

The uranium-lead methods, which are still regarded as standards of comparison for other types of age determination, have been undergoing much study and are being applied by the Carnegie group (1956–7) in determining the ages of accessory zircon in granites. The analysis of the trace amounts

of lead and uranium in slightly radioactive zircons has again been made possible by the advances in mass spectrometric techniques.

A study of particular interest to Maritime geologists has been undertaken by a group at the Massachusetts Institute of Technology (Fairbairn, 1956–7). Micas from a number of granites from Nova Scotia and Cape Breton Island have been dated, mainly by the rubidium-strontium method. Both biotite and muscovite have been used and in several cases the results have been checked by the potassium-argon and the lead-uranium methods. If Holmes' (1947) time scale is accepted, the granites of this region were emplaced during the Middle and Upper Ordovician. The maximum differences in age found by the M.I.T. group may represent a real difference in age of the granites. A parallel investigation of ages in New England and Quebec suggests that the granites in the Green Mountains area are Middle Silurian to Lower Devonian in age. The M.I.T. group has also commenced a study of the ages of biotites from Sudbury which should materially assist in determining the age relationships of the geological formations in the Sudbury basin.

Work being done by several other groups in the United States has added to our knowledge of the ages of Canadian rocks. Investigators at the Carnegie Institution of Washington (Wetherill *et al.*, 1957) have made a study of rocks from the area north of Lake Huron including some samples from the Sudbury area. Their preliminary results indicate that there appears to have been an episode of mineralization at Sudbury about 1,350 million years ago. It is worth noting that the rubidium-strontium and potassium-argon ages were not found to be in good agreement for the Sudbury samples.

A group at the University of Minnesota (Goldich *et al.*, 1957) has commenced a programme of potassium-argon age determinations on micas from rocks in the Minnesota-Michigan area, and some samples from the Duluth gabbro complex have been dated, as well as granites cutting the Thomson formation of east central Minnesota. Geological correlation of the Thomson with the Biwabik and Gunflint formations is possible and may enable the group to place a lower limit on the algal and other fossil remains in these formations.

Members of the mass spectrometric laboratory of the Geological Survey of Canada have published several age determinations made on uraninites from the Blind River area of Ontario (Wanless and Traill, 1956). The results show that at least two ages of uranium mineralization exist in that area, one approximately 1,200 million years in age, the other 630 million years in age. There is some indication that this area may present the same complexity as the mineralization in the Goldfields, Saskatchewan, region.

The many isotopic and chemical analyses made on Goldfields pitchblendes by various groups in Canada and the United States are still under discussion. A simple method of examining discordant lead age data from a particular area has been proposed by Wetherill (1956). If it can be assumed that the

original age of deposition of all the samples was the same, and that the loss of lead or uranium responsible for the discordancy among the ages occurred at the same time for all the samples, then it is possible to determine both the original age of deposition and the time at which the alteration took place. Russell and Ahrens (1957) examined the data for a number of samples from the Ace Mine, Goldfields, and noted that the discordances in age reflect the mechanism by which the lead was lost from these minerals. It had previously been assumed that the lead isotopes were removed impartially from the pitchblendes by some chemical leaching process. Russell and Ahrens suggest that the physical process of nuclear recoil during the decay of uranium to lead is primarily responsible for placing lead and other decay product atoms in sites where chemical leaching might remove them from the mineral.

Investigation of the variations in lead isotopes in galenas has been continuing at the Geophysics Laboratory of the University of Toronto. A number of isotopic analyses of galenas from areas near contacts of Huronian-type and Keewatin-type rocks have been made recently (Farquhar and Russell, 1957). Galenas from the Thunder Bay region, Ontario, have received additions of the radiogenic lead isotopes, lead-206, lead-207, and lead-208 previous to their deposition. These additions have probably come from rocks local to the place of deposition of each of the deposits sampled,

TABLE I

RESULTS OF AGE DETERMINATIONS ON CANADIAN ROCKS AND MINERALS
(For results of actual analyses, see original references)

Location	Material	Ref.	Ages based on			
			Pb^{206}/U^{238} ($\times 10^6$ years)	Pb^{207}/U^{235} ($\times 10^6$ years)	Pb^{207}/Pb^{206} ($\times 10^6$ years)	Pb^{208}/Th^{232} ($\times 10^6$ years)
Fission Mine, Wilberforce, Ont.	Uraninite	(1)	1040±30	1050±30	1070±50	1010±30
Cardiff Mine, Cardiff Twp., Ont.	Uraninite	(1)	1020±30	1020±30	1020±50	995±30
Viking Lake, Sask.	Uraninite	(1)	1790±50	1830±50	1870±50	1640±50
Tory Hill, Ont.	Zircon from granite	(1)	1030	1050	1090	390
Tory Hill, Ont.	Zircon from Syenite	(1)	940	960	1015	—
Cardiff Mine, Cardiff Twp., Ont.	Zircon	(1)	900	930	1000	990
Algom,-Quirke Lake, Ont. 4th level, Eastface	Uraninite	(2)	1170	1300	1400	1265
Pronto Uranium, Ont. Underground drift	Uraninite	(2)	630	600	590	—

TABLE I (*continued*)

	Material	Ref.	Ages based on A^{40}/K^{40} ($\times 10^6$ years)	Ages based on Sr^{87}/Rb^{87} ($\times 10^6$ years)
Fission Mine, Wilberforce, Ont.	Mica	(1)	960±50	1000±50
Cardiff Mine, Cardiff Twp., Ont.	Mica	(1)	1000±50	1030±50
Viking Lake, Sask.	Mica	(1)	1850±80	1970±50
Hearst Pegmatite, Sudbury Area, Ont.	Lepidolite	(3)	2605	2595
Wavy Lake granite Sudbury Area, Ont.	Biotite Mica	(3)	1025	1075
Cutler Batholith Sudbury Area, Ont.	Biotite Mica	(4)	1380	1325
Bear River, N.S.	Mica (from Granite)	(3)	388	370
West Nictaux, N.S.	Mica	(4)	395	305
Lake Gaspereau, N.S.	Mica	(4)	388	370
Albany Cross, N.S.	Mica	(4)	388	365
St. Margaret's Bay, N.S.	Mica	(4)	345	315
Ship Harbour, N.S.	Mica	(4)	390	400
Larry's River, N.S.	Mica	(4)	320	330

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and make it possible to calculate an upper limit of 1,700 million years for the time of deposition of the leads. It may be possible, when more samples have been analysed, to determine the general direction of movement of the solutions from which the leads were deposited.

It is clear from this very brief summary of the progress in methods and results in the field of absolute age determinations that the future appears far brighter than it seemed a few years ago. The significant results which have appeared in the literature during the past year have been tabulated in Table I. The only problem of any consequence is whether the difficult and often tedious techniques which have been developed for obtaining ages will be taken up and applied in routine fashion by geologists. This step is important because several of the laboratories mentioned in this report are primarily interested in the development of methods rather than their widespread application. If geologists are willing to apply absolute age determinations to their purposes with their customary energy and enthusiasm they will find themselves possessed of a most useful and accurate tool.

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SYMPOSIUM ON HYDROLOGY

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Ground Water Comes of Age in the United States*

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Presented by J. M. HARRISON, F.R.S.C.

ABSTRACT

The investigation of ground water as performed by the United States Geological Survey, largely in co-operation with State agencies, includes three phases. In different investigations these are mixed in infinite variation, according to the needs of the investigation and to the personnel available.

The first phase and the one that consumes the largest part of our energies includes the areal investigations. These are systematic studies designed to locate and appraise the ground-water supplies of the nation, area by area, to determine the quantity and chemical quality of the water and its replenishment, movement, and discharge through springs or wells.

The second phase is research into the physical laws governing the occurrence and movement of ground water in relation to such subjects as replenishment of the aquifers by natural or artificial means, causes of land subsidence, nature of intrusion of salty water into freshwater aquifers, and conservation and development of ground-water resources.

The third phase is the maintenance of a current record of the status of the ground-water resources by measuring water levels and artesian pressures in wells.

The Survey is authorized also to locate and appraise water supplies for other Federal agencies, but it does not do so for private individuals, industries, or municipalities, although it is authorized to co-operate with municipalities in investigations in which the municipalities' interest is in water for public supply; nevertheless the Survey's interest is in the availability of water for any and all uses. Some of the State organizations are authorized to make specific studies to meet private and municipal needs. A growing body of trained consultants also is available for this purpose.

The paper discusses the methods and organization by which these activities are carried out, and the development of this programme during the history of the U.S. Geological Survey.

I WAS honoured when Dr. Gunning asked me to participate in this symposium on "Hydrology." The invitation pleased me especially because it reflected a radical change in the thinking about water, not only among geologists but also among informed laymen. This evolution is significant because, despite some danger of over-simplification, I believe we can draw two basic generalizations about water: our water supply will be one of the principal factors limiting the extent of our national growth, and the course of that growth will depend upon our ability to utilize to the fullest extent the sources of water which are now available to us or which remain to be discovered and made available for use. This growth can be realized fully only if our knowledge of water resources, of their conservation, and of their

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prudent use gains a lead over current needs, instead of lagging behind as it does in many parts of the nation today. This is our debt to the future, toward which we must make a substantial payment.

I feel this debt very strongly. Still, as Spartacus said to the gladiators at Capua, "It was not always thus." When I first joined the Geological Survey nearly thirty years ago and was assigned to the Ground Water Branch, I was rather disappointed. I had hoped to be assigned a nice clean stratigraphic problem, preferably in a petroleum-rich area in which I might feel at home, and in which my earlier experience would be of great usefulness.

Like most geologists, I had little interest in water, except as a geologic agent. I knew that it was responsible for erosion of the land and deposition of sediments, that it actively dissolved soluble minerals under certain conditions and deposited them under other conditions, that it played an important role in the deposition and enrichment of certain ore deposits, and that it served various other useful and not-so-useful purposes, but I had never considered seriously the problem of water supply and how it is obtained. I believed this to be the province of the engineers and the well drillers.

I soon learned the depth of my ignorance, but I found also that most of my fellow geologists were equally ignorant. At that time, the Ground Water Branch of the Federal Geological Survey, under the late O. E. Meinzer, the several State Geological Surveys, and private persons, had discovered and described most of the major ground-water reservoirs. Their location, thickness, and lateral extent, the chemical quality of their waters, and the current artesian pressure were moderately well known. But, for the most part, the approach was simply qualitative. The reports described the surface and subsurface geology and included such quantitative information on well yields as could be obtained from local residents and well drillers. However, it was rare that an attempt was made to measure the static water levels in wells, or the drawdowns when the wells were pumped, or the discharge of flowing wells and their pressure when shut in and when flowing, and so on. Still less was there any attempt to determine the amount of water that could be extracted from an aquifer as a whole in a given area.

In general, when a man wanted a well-water supply he obtained the services of a well driller, who quite commonly claimed some ability as a water dowser. Occasionally a professor of geology was called upon to assist in siting a well in difficult terrain, and some State Geological Surveys provided similar advice. One or two consulting geologists specialized in groundwater investigations, but they found it necessary to supplement their income from this source with fees for engineering geology or other types of geologic work. Such quantitative work in ground water as was done was done chiefly by engineers. Only a few of the long list of pioneers in this field can be mentioned here. A more complete catalogue will be found in a review paper by John G. Ferris and myself entitled "A quantitative approach to groundwater investigations," which was published in 1956 in the Fiftieth Anniversary Volume of Economic Geology.

In France, Henry Darcy, the centennial of whose best known paper was celebrated at Dijon this past year, demonstrated that, within the limits of experimental error, the rate of vertical flow per unit area through cylinders of sand was directly proportional to the hydraulic gradient. This became the fundamental concept of ground-water movement through porous media. Jules Dupuit, a contemporary of Darcy's, made certain assumptions of ideal flow through porous media and wrote the fundamental differential equation for the steady-state flow of ground water. He noted that, with the introduction of the porosity term, his theoretical equation took the form of Darcy's law and was thereby confirmed by Darcy's experimental observations. However, to test his theory on a pumped well he needed ideal conditions of hydrogeologic controls that were not available. In Germany, much of Dupuit's theoretical analysis of ground-water flow was repeated by Adolph Thiem, who in 1870 developed equations for flow toward wells and galleries which proved extremely useful in calculating the radius of the cone of depression surrounding pumped wells. His son, Gunther Thiem, pointed out that the Dupuit-Thiem equation could be applied to two intermediate points on the profile of the cone of depression, and with this modification the formula became a practical tool for determining the permeability of water-bearing deposits in situ.

The work of the Thiems, together with that of Phillip Forchheimer of Germany and C. S. Slichter of the United States, identified for the first time the nature of Darcy's constant of permeability and formed the basis for the pumping test now commonly used, in which, by measurements of the pumping rate in a pumped well and of the water levels in it or in nearby wells, the rate of transmission of water through a known aquifer can be established. Later work by C. V. Theis of the United States resulted in the introduction of the coefficient of storage, which enables computations of nonsteady-state flow and provides a means for predicting the effects of pumping at different times and places.

But I am getting ahead of my story. In the first decades of this century, with engineers and physicists working more or less in isolation from the geologists, the value of the discoveries of Slichter and his predecessors was only partly or locally appreciated. Inasmuch as the occurrence and movement of ground water depend to a large degree on a geologic environment that is rarely homogeneous, an understanding of the geology is essential to a reasonable knowledge of the behaviour of the water. O. E. Meinzer, late chief of the Ground Water Branch of the United States Geological Survey, conceived the idea of utilizing the talents of both engineers and geologists on the same problem, and so he assigned A. G. Fiedler, an engineer, and S. S. Nye, a geologist, to an intensive study of the Roswell basin in New Mexico, where the artesian pressure was declining so rapidly that the irrigators who depended on flowing wells were faced with financial ruin. In a masterful study these men reached quantitative conclusions as to the areal extent of the aquifer, the area of its replenishment, the rate of replenishment, and the

rate of discharge. The legal controls established by the State as a result of this pioneering study brought the ground-water use under control and re-established the prosperous agricultural economy that had existed in the area many years earlier. Moreover, the value of scientific ground-water studies was thoroughly demonstrated.

The completion of this work was followed shortly by the great drought of the early thirties, which forced thousands of families in the Plains States to abandon their farms and made it apparent that much of the area west of the 100th meridian was destined to be forever on the margin between drought and plenteous rainfall. At that time also the normally abundant precipitation of the area east of the 100th meridian was far below average; many towns and cities accustomed to abundant supplies were forced to ration water, and pastures and many forested areas turned brown. As the deficiency in precipitation spread it became a national tragedy. The Midwest became a huge dustbowl where the sky was darkened by clouds of dust for days on end.

Thus began what might be termed the era of conservationism—the attempt to protect our soils and water supplies by afforestation or reforestation, contour plowing, planting tree belts, constructing dams and levees, and so forth. It brought also a steadily increasing demand for factual information about our water supplies. Although precipitation returned to normal or above in the late thirties, the requests for information continued to rise rapidly as World War II brought an ever increasing need for water. The demand has continued to increase at nearly the same rate up to the present. It is estimated that the use of water in the United States increased more than 600 per cent from 1900 to 1950, and from 1950 to 1955 it increased another 35 per cent.

Throughout history the lack of power for raising water to the land surface has hindered the use of any water that could not be delivered by gravity. Thus surface water, flowing artesian water, and, where labour was cheap, shallow ground water were developed first. But large reservoirs of ground water were beyond reach because the water was too deep to be exploited by primitive methods. Since the beginning of the twentieth century, however, power from steam, electricity, gas, and oil has become relatively cheap. Great improvements have been made in well construction, so that it is now possible to lift large quantities of water hundreds of feet at reasonable cost. Most of the best dam sites have been occupied, and in order to maintain the expanding economy we have turned more and more to ground-water sources.

In 1935 the total use of ground water in the United States was about 10 billion gallons a day. By 1945 it was something more than 20 billion gallons a day, by 1950 about 30, and by 1955 nearly 46 billion gallons a day. The total use of fresh water, exclusive of power generation and nonwithdrawal uses such as navigation and waste disposal, was about 221 billion gallons per day in 1955. Thus, ground-water sources supplied about a fifth of the total in 1955 as compared with about a sixth in 1950.

Although the study of ground water and that of surface water require the use of different disciplines, the two resources are closely interrelated and conditions that affect the one affect the other. Our best estimates indicate that between a third and two-fifths of the surface run-off in the United States is provided by discharge from ground-water reservoirs. If this is correct, it may not be illogical to anticipate that, when full development of our water resources is realized, something like 65 per cent of our supplies will come from surface sources and about 35 per cent from ground-water sources. Such a balance would mean that the assets and liabilities controlling the use of surface water would have to balance those controlling the use of ground water. In any event, before such a balance is reached, we must have greatly expanded our knowledge of our water resources and the interrelationships among precipitation, run-off, ground-water storage, evapotranspiration, and other phases of the hydrologic cycle.

Five types of use account for most of the withdrawal of water from streams and wells: public supplies, rural supplies, irrigation, self-supplied industrial uses, and waterpower. The reasons for the increased use of water for all these purposes are related to and intimately connected with the rise in living standards and the enormous acceleration of our technological development. In the rural areas almost every successful farmer has indoor plumbing, which increases his use of water many times over that of the old days. All except the smallest towns have central water-supply and sewerage systems. Modern washing machines, dishwashers, and other water-using devices are almost standard equipment in newer homes. Air conditioning is estimated to increase city water use very substantially. In Washington, D.C., on a typical hot day the use for cooling is about 80 million gallons, raising the average cool-day use by more than 60 per cent.

In 1955 about 34 million acres of land was under irrigation in the United States. Irrigation is generally considered to be reserved for arid regions, but there is probably not an unirrigated farm in the country the yield of which would not be improved by irrigating some of its land during crucial times of deficient rainfall. The eastern part of the United States has accepted this idea with enthusiasm, and irrigated farms are now commonplace. The increased productivity generally pays for the initial cost of the installation within the first year or two.

The use of water for carrying waste is very important in an industrial economy. Carl E. Schwob of the Public Health Service has reported that in 1955 the effluent from sanitary sewers and industrial outlets being discharged untreated into our streams was equivalent to the wastes from 150 million people. This will become an increasingly difficult problem unless the steps now being taken to correct it are accelerated.

In addition to the normal increase in water use due to the expanding population, whole new classes of industry, requiring huge quantities of water, have developed in recent decades. To mention just a few of the products,

we have synthetic rubber, synthetic fuels, synthetic fibres, refined petroleum, and plastics.

Water has become, even in the humid East, a valuable commodity. A measure of its increasing value in the United States is the number of people engaged in solving water problems. Thirty years ago there were scarcely a dozen men in the Ground Water Branch. There are now more than 550 geologists, engineers, physicists, mathematicians, and technicians on its staff. Several of the states have organizations of six or eight men working on ground water. In addition, there are at least a dozen consulting firms that deal exclusively with ground water. Incidentally this has caused a heavy drain on my branch because many of them consist mainly or entirely of "alumni" of the Ground Water Branch. A similar expansion has been observed in the workers in surface-water investigations.

It should be recognized that only a small part of the water used for various purposes is actually consumed; most of the consumption is accounted for by irrigation. Only a small part of the water used by industry is consumed, but much of it is so badly polluted by objectionable wastes that it cannot practicably be used again. Water used for municipal, rural, and many industrial supplies, however, can be purified and reused for other purposes. There is, therefore, great opportunity to conserve water by more effective purification and economical use.

Despite serious and prolonged droughts that afflict certain parts of our country and despite local shortages caused by excessive withdrawals, the evidence from our observation wells and stream-gauging stations does not indicate that the total supply of water has diminished since the beginning of the records, many of which go back more than sixty years. Nevertheless, if water use and pollution continue to increase and the total amount of water supplied by precipitation remains nearly constant, we must look forward to the day when supply and use will be equal and water supply will become a factor limiting further expansion of the country as a whole, as it already is in a few areas.

I believe that this day is far distant if we recognize the problem and take the proper steps to meet it. These may be outlined as follows: first, systematic location and quantitative appraisal of our ground- and surface-water resources; second, periodic measurements of streams and key wells to ascertain long-term trends; third, continuing research into the physical laws that govern the occurrence of water and determine the interrelations among precipitation, land and forest management, and ground- and surface-water supplies; and fourth, the establishment of such water-conservation measures as may be necessary. The first three are the province of the scientist; the fourth is the responsibility of the engineer who plans the works, the legislator who appropriates the money for them, and the layman for whose benefit, and at whose expense, the whole job must be done.

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Water Conservation Studies on the East Slopes of the Rocky Mountains

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Presented by J. T. WILSON, F.R.S.C.

ABSTRACT

Reference is made to the Acts of Parliament which have given corporate life to the Eastern Rockies Forest Conservation Board, the reason for the Board's formation, and its terms of reference as applied to water conservation. The Board's approach to the problem is explained with the studies and surveys it has undertaken. The progress of these researches to date, the tentative conclusions drawn from them, and the future possibilities are dealt with.

THE Saskatchewan River is the only stream serving the wheat belt in the southern portion of the Prairie Provinces of Canada which provides a high volume of summer flow. In northern Alberta the Athabasca and Peace rivers serve an agricultural area but they flow northward into the Arctic. In southern Alberta the Milk River arises south of the International Boundary, but after flowing for about one hundred and twenty-five miles through Alberta it returns to the United States. With the sparse precipitation normal on the Canadian Prairies the summer flow of the streams originating on them becomes negligible as soon as the spring floods have receded. There are several localities totalling many thousands of square miles that have no outlet to the sea and evaporation alone disposes of the waters distributed on them. Finally, the Winnipeg River and the other streams flowing into Lake Winnipeg from Ontario do not serve any considerable area of farm land in Manitoba.

It may, therefore, be stated that the portions of the three Prairie Provinces lying south of the 54th parallel will be dependent upon the waters of the Saskatchewan River for the majority of all irrigation projects in the future and for much, if not most, of the hydro-electric development within the area. One can, therefore, appreciate the importance of this great river in the future of Canada.

A large part of the summer flow of the Saskatchewan comes from melting glaciers. Whatever the reason for glacier recession on the east slopes of the Rocky Mountains, it has been evident for several decades that some of the smaller glaciers have disappeared or are disappearing at an alarming rate and even the largest ones, such as the Columbia ice-fields, are receding at a rate which, if maintained, will become a serious element in diminished summer flow of the streams they feed. How long this recession has been going

on, and whether or not it is cyclical, is not yet definitely known. There is generally supposed to have been an upward trend in average temperatures since the commencement of the present century which, if actually the case, could have accelerated the disintegration of the ice-fields. A study of available statistics does not seem to substantiate this belief.

This glacial recession and its effect on the flow of the Saskatchewan River has, for a couple of decades, been a matter of concern to some of our more far-sighted scientists and statesmen and, fortunately, action has been initiated toward a study of the problems involved and to seek methods to offset the diminishing flow of the Saskatchewan. This, if unchecked, could have serious, if not drastic, repercussions throughout our wheat belt within a few more decades.

The action taken by the governments directly involved resulted in reciprocal legislation between the federal Government and the Government of Alberta which became effective in 1948. Through this legislation the Eastern Rockies Forest Conservation Board came into being with funds provided to study the needs of the situation and to carry out the works necessary to administer, in conformity with these needs, the Provincial Forest Reserves which lie on the watershed of the Saskatchewan River outside the National Parks. The agreement between the governments is for a twenty-five year period ending in 1973.

The Forest Reserves enclose roughly 9,000 square miles above the 4,000 foot contour, and drain into the Saskatchewan River. They commence at the northern limit of Waterton Lakes Park some twelve miles from the International Boundary and lie along the boundary of British Columbia and the continental divide until the southern limit of Banff Park is reached after which their western boundary coincides with the eastern boundary of that park and Jasper Park.

Although the area within the forest reserves is relatively small it is the main source of summer flow for the Saskatchewan River. In August, 1949, stream measurements taken indicated that almost 95 per cent of the flow of the South Saskatchewan River at Medicine Hat originated in the forest reserves and Banff National Park although they constitute little more than 10 per cent of the drainage area involved.

Under the Eastern Rockies Forest Conservation Act the federal Government provided $6,300,000 for capital expenditures on the forest reserves during the first seven years of the agreement and in those earlier years of the Board's existence it took a major share of the maintenance costs. The province of Alberta carried a portion of maintenance and administration costs in the early years, but has since agreed to assume the full cost of continuing the studies undertaken and of maintenance and administration of the area.

The name of the Board and of the Act creating it would imply that forestry is its major duty, but this is not actually the case. Its major duty is to provide flow of water, particularly summer flow, for the Saskatchewan

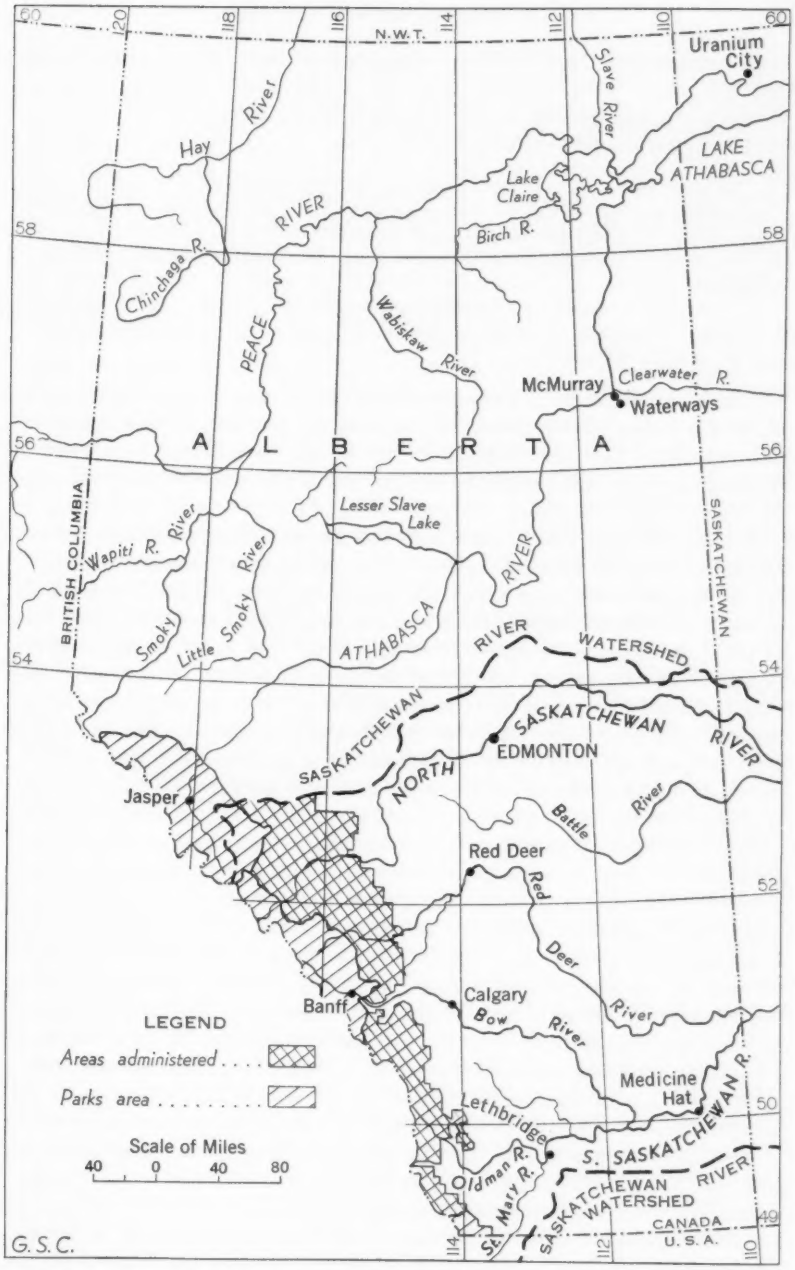

FIGURE 1.—Map showing the areas administered by the Eastern Rockies Conservation Board.

River and forestry is one of the most important tools to be used in achieving that end.

The Act passed by both parliaments in 1947 states in part:
The purposes or objects of the Board are—

(*a*) To construct, operate and maintain and to supervise the construction, operation and maintenance of projects and facilities required for the conservation of the forests and the protection of the watersheds in the area.
(*b*) To protect the forests in the area from fire, insects, disease and other damage; and
(*c*) To conserve, develop, maintain and manage the forests in the area with a view to obtaining the greatest possible flow of water in the Saskatchewan River and its tributaries.

This last item has been accepted as the ruling clause in the Board's terms of reference, but it interprets it as meaning the greatest possible *regulated* flow. Actually, the greatest possible flow would be achieved by removing the vegetal cover and letting the stream flow alternate between flood conditions and minimum flow.

The Board's approach to the task set was first to make it possible to protect and administer the area through the construction of a comprehensive road system and the installation of an ultra high frequency radio coverage, both of which provide widespread facilities to all portions of the reserves. Previous to the formation of the Board there had been little access to the reserves except by packhorse so it was found necessary to build a road system suitable for rapid motor vehicle movement. There are now over 900 miles of roads on the forest reserves. Two hundred and seventy-four miles of this total are high speed gravelled roads with good grades, curves and bridges, one hundred and seventy-six miles are narrower, secondary roads, bridged and gravelled where necessary to maintain travel throughout the late spring, summer and fall. Five hundred and ten miles are ungravelled bulldozed trails providing access by power transport to major watersheds and lookouts.

An extended fire lookout system with wide coverage has been developed and it has been linked by radio with ranger stations and the various district headquarters. Excellent accommodation has been provided for forest rangers throughout the area and all rangers are equipped with, and trained in the use of, modern fire-fighting equipment and mechanical transport. Ranger stations are equipped as weather stations and systematic meteorological recordings are taken daily. Despite some high fire hazard periods, the total area burned over during the eight years of the Board's administration amounts to little more than one-tenth of one per cent of the area involved.

The forest superintendents and rangers, all of whom are members of the Provincial Forest Service, not only serve as protectors of the forest, but also administer the game laws and supervise all cutting operations and tourist activities within the area. More than 135,000 tourists travelled the roads last year.

Concurrent with developments leading toward protection and administration of the Forest Reserves, various surveys have been carried out. These include: a forest inventory; a soil survey; a vegetal survey; accumulation of stream flow data (meter readings are taken by the Water Resources Branch of the federal Government and include data from thirty-four metering gauges in the area, fourteen of which were installed for the Board by the Water Resources Branch); and accumulation of meteorological and precipitation data from fourteen weather stations and ninety-six precipitation gauges installed by the Board. These data are in addition to that supplied by the Department of Transport in adjoining areas.

The Board has become aware that water conservation measures and sound forest management from the standpoint of timber production sometimes conflict. For instance, a timber producing forester would normally refuse to tolerate grazing within his forests, but it is encouraged on much of the east slope area. Grazing animals keep the vegetation on untimbered areas cropped, thus reducing fire hazards in spring and autumn when unpastured dry weeds or grasses would speed the spread of any blaze that got under way. Animals also reduce the underbrush in some types of forest where open rather than closed stands are preferred. Also, the Board believes, although it is not yet clearly proven, that transpiration losses, an important element in our lower altitudes, are less on grazed lands than in dense forests.

The type of forest which will effect the optimum in regulated flow is a shallow-rooted forest of sufficient density not only to slow down the melting of winter snows, but also to provide a covering of litter on the ground to slow down lateral surface flow. At the same time, the roots, through wind action on the tops, loosen the soil, thereby facilitating water penetration. Therefore, the Board will favour shallow-rooted trees such as spruce as compared to deep-rooted species such as poplar. Area of leaf surface is a major factor in transpiration and this is true whether the coverage is of trees, shrubs or grasses.

Board policy is aimed at harvesting the forested areas in such a manner as to avoid erosion and to provide a forest succession which will slow down run-off and tend to coax water into the soil for slow release over long periods. The systems applied vary from clear cutting to no cutting. Clear cutting applies to badly over-mature stands while prohibition of cutting applies to steep slopes where removal of existing forest cover might set up possibilities of dangerous erosion.

Experiments undertaken elsewhere indicate that partial cuttings can be used as a tool to increase regulated flow. Studies are now under way on the slopes in strip cutting, thinning, etc. and, in the long-term approach, the species and type of forest which uses the least water during the summer will be preferred. To date there is no clear-cut evidence as to the desirability of, say, spruce over lodgepole pine or Douglas fir, but over the years information of this nature will be acquired and used.

As there is a considerable population of grazing game animals, particularly elk, moose, sheep, etc., there is competition for grazing in various areas, and any tendency toward over-grazing is adjusted with a view to maintaining a satisfactory game population. In the southern portion of the reserves elk for a time became so numerous that their winter ranges were over-grazed and they descended to the farmlands thereby competing with domestic animals. On the Board's recommendation, lengthened open seasons for the hunting of elk and the shooting of does were permitted. In a couple of years a satisfactory balance was achieved and the ranges restored.

In the northern areas the thousands of wild horses have caused serious deterioration in vegetal cover over large areas and methods to eliminate them are now to be attempted. They are not game animals and have little commercial value in their wild state, except for rodeos.

When the Board was formed it became evident that there was comparatively little knowledge of existing conditions or of what might be done to maintain or improve the situation as regards water conservation in the area. Worse still, there were little useful basic data available which could be applied with regard to run-off, rainfall, temperatures, precipitation, wind currents, velocities of wind, and so on. Weather records for cities such as Edmonton, Calgary, Red Deer, Banff, etc., were available over a considerable period, but the accumulated data could not be applied to the east slope Forest Reserves.

Few streams on the slopes had been metered for flow and fewer still were the weather stations in the mountainous regions. Data which the Board have since accumulated from various studies indicate tremendous variation in both summer and winter precipitation within relatively short distances and these variations vary from east to west and from south to north. Altitudes on the Forest Reserves range between 4,000 feet and 10,000 feet above sea level. Precipitation varies from about twenty inches to upwards of seventy inches with altitude the dominating factor.

Stream flows vary widely with the seasons and glacial-fed streams can cause serious irregularities in the records, sometimes indicating considerably more run-off than is to be anticipated from precipitation data corrected for losses from transpiration and evaporation. It is fairly obvious that the excess of stream flow occurs because the glacier source is being used more rapidly than we might wish. Data obtained do not yet furnish a clear correlation between temperatures and glacial flow, nor between flow originating from snow of the previous winter and that from ice stock-piled over previous centuries in the glaciers.

It has been ascertained that the heavy spring and summer downpours in the more southern portion of the reserves arise from moisture originating in tropical Caribbean regions which reaches the Rockies without having encountered altitudes to cause it to be discharged. Rainfall of several inches in an afternoon over limited areas, with a spectacular increase in stream flow within a few hours, is not unusual. On the other hand little summer pre-

cipitation arises from clouds crossing the mountains from the Pacific, these clouds normally losing their moisture on other mountain ranges before they reach Alberta. However, the area does receive heavy snowfalls originating from Pacific moisture. This occurs as a sort of backfall from clouds travelling at such altitudes that the snow from them does not reach the earth's surface until it is east of the continental divide.

Naturally, many contradictory data have been found during the seven years spanned by the Board records. For instance, there have been two abnormally wet summer seasons. This has upset summer precipitation averages so seriously that it will take several normal seasons to offset their effect. In fact, if the average of the past five years of summer precipitation were taken it would indicate that there would be little need for serious water conservation measures in the area. This, we believe, would not be a true picture of long-term needs.

Board studies indicate that there is relatively little storage available in reservoirs that might be created economically within the forest reserves. This is because the country is too precipitous and the valleys generally too narrow to impound large volumes of water except at prohibitive cost.

There is little vegetation above the 7,000 foot level and large areas of barren rock predominate in the higher levels which generally receive the heaviest precipitation. The most useful soils in which to store water lie in the valleys and on the moderate slopes. Soil surveys already carried out indicate the areas where conservation effort may best be concentrated.

Studies are not sufficiently advanced to estimate how effective concentrated effort in water conservation may be. From the beginning it has been clear that flash floods will not be eliminated although their effect may be somewhat minimized. Conditions will continue to arise causing the streams emerging from the east slopes to go on the rampage.

In its studies the Board maintains continuous contact and exchange of data with the Forest Service and the Soil and Water Conservation Services in the northwestern states of the United States. From these contacts and from the Board's studies the signs are promising that considerable progress may be made towards maintenance of a significant portion of the stream flow which would otherwise diminish because of glacial recession over the decades.

It is realized that the demand for water from the Saskatchewan River will increase with the expansion of irrigation projects and with the increase in population. Expanding industrialization also will aggravate the situation when the water scarcity becomes noticeable.

Fortunately, however, the problem has come under study some decades before the needs are likely to become critical and the gaps now existing in data and in knowledge of how to solve, economically, the problems of regulated flow should be eliminated before that time.

Board studies indicate that surface storage within the Forest Reserves cannot furnish the main answer to summer flow and that the most effective solution lies in using the soil mantle overlying the area as a reservoir. In-

formation is already available as to the areas in which this approach may be applied most effectively and the Board is experimenting with the most suitable types of vegetal cover to achieve maximum water storage with minimum loss through transpiration, interception or evaporation. It has been demonstrated elsewhere that spreading water from the various streams on the slopes over the more easily penetrated areas is feasible, but expensive. As yet such action is not justified.

The Board does not believe in maintaining a wilderness area as is urged by some interested groups and as is practised elsewhere, but, on the contrary, believes that the best and most economical results may be obtained by using controlled commercial harvesting of timber and controlled grazing as tools in achieving its aims. It is possible through use of methods already tested to assist nature in maintaining the flow of the Saskatchewan River.

The Board realizes that it is only on the threshold of the studies required and the development of works which will be necessary in a long-term programme of maintaining a reasonable flow in the Saskatchewan River. However, it is felt that it is relatively safe to state a few principles and make some generalized predictions. Taken together these might be regarded as a basis for Board policy. They are as follows:

1. There will continue to be an increasing demand for water in the Prairie Provinces and its availability may well become the limiting factor in expanding development of portions of the region.

2. There is almost certain to be some decrease in the "natural" flow of water from the mountain areas owing to the shrinkage of glaciers.

3. As in the case of natural resources elsewhere, coincident with economic expansion there will inevitably be an increasing pressure on the part of industry to expand the usage of the chief products of the forest reserves. Commercial abuse of the resources could prove disastrous, but their commercial use is economically necessary for the cultivation of optimum watershed conditions.

4. Methods of increasing the water yield of forest areas are already known and other methods will be evolved in time. But, until the need for greater supplies of water are actually upon us, the first duty of the Board should be to build up the potential water storage capacity of the region.

5. Apart from the water yield, the resources of the region give much-needed support to the local economy and are important ingredients in the national well-being. This fact should not be obscured in the quest for more water.

6. With reasonably conservative management the catchment should produce adequate water in normal years. Refined management must aim at achieving the maximum flow in dry years, or in a succession of dry years, when the need becomes urgent.

7. The methods of achieving maximum flood control and of encouraging optimum run-off are, to a great extent, diametrically opposed. Because the most pressing need is for water in drought periods, some chances will even-

tually have to be taken with local floods at infrequent intervals. The effects of these can be mitigated by works created outside the reserve.

8. The soil mantle is incomparably the greatest water reservoir at man's disposal. Its careful conservation may obviate the need for costly dams and in any event will improve the conditions under which such man-made reservoirs function.

The foregoing statements suggest long-term policy. It implies the "multiple use" concept of forest lands under which all legitimate uses are given due consideration. Often this concept is difficult to apply because of the conflicting interests of the various classes of forest users. On the east slopes, however, this situation is partially solved because of the fact that it is not the interests of any local user of the forests, but of the dweller further east on the Prairie which must predominate over other considerations.

For the present, then, the Board's management policy is to bring the resources of soil and vegetation into the most healthy state possible through judicious use coupled with protection of the forests against fire and disease. As time passes and the consumption of water approaches the present capacity of the area the emphasis will have to shift. The process of gradual enrichment of the moisture-storage capacity of the area will have to give way to one of a more daring character involving highly specialized and closely controlled exploitation designed to coax forth every drop of water not actually needed for the maintenance of thrifty growth in selected areas. This evolution of policy will probably be fairly slow, and is likely to progress from one drainage area to another in response to special regional demands for greater amounts of water.

In the preceding paragraph I have mentioned that more daring expedients may be necessary if water shortage on the Prairies becomes a limiting factor in further development. When this condition is reached, costly measures which could not formerly be justified will become feasible and the controlling agency may experiment with projects such as the erection of gigantic snow fences in strategic locations at high altitudes to precipitate the heavy snowfalls in deep valleys where it may melt slowly throughout the summer. Or the winter flow of streams in the wider valleys might be dammed and spread out widely during the period of low temperatures, thereby forming artificial glaciers whose melting period would extend through most of the summer months.

As water becomes more precious such expedients may well prove practical. They are as yet only the day-dreams of some of us who have endeavoured to look a century or more ahead when the world population will be double or more than double its present figure and Canada's Prairies will not suffer from annual wheat surpluses but will be one of the major food sources available to feed the world's hungry multitudes.

I am sorry that more specific data are not yet available and that this paper has, perforce, been limited to a narrative of the physical aspects of the project allotted to the Eastern Rockies Board with only a rough forecast of

possible events and studies which may take place in the future. The Board's efforts are still in their infancy, but those of us who have dealt with the work to date are not unhopeful of worthwhile results nor are we disillusioned concerning the time that will be taken in finding correct answers to the many problems which will arise.

One of the very satisfactory achievements to date has been that the Board has already become self-supporting in that surface revenues from the area now amount to more than the cost of maintenance and administration. This is largely due to the sale of timber resources, mostly over-mature, and new grazing areas tapped by the road system provided. This was an unexpected but gratifying result of the first decade's operations. The Board's hope is that succeeding decades will produce other equally satisfying, but more important, results.

TRANSACTIONS OF THE ROYAL SOCIETY OF CANADA
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SECTION FOUR

Hydrometeorology and its Applications in Ontario

J. P. BRUCE
Presented by H. C. GUNNING, F.R.S.C.

ABSTRACT

In recent years, an increasing awareness has developed of the contributions meteorology can make to the understanding of hydrological problems. The resulting branch of applied meteorology, known as hydrometeorology, is concerned mainly with two general problems. These are (1) providing estimates of future storm and flood magnitudes and their probabilities of occurrence as design criteria for river structures, and (2) developing techniques for and operating river forecasting and flood warning systems. Techniques used in solving these problems are outlined, and examples given of application of the methods to Ontario rivers.

THE hydrologic cycle defines the general circulation of water from the seas to the atmosphere, to the ground and back to the seas again. Many branches of science are concerned with the various phases of the cycle, but those most directly involved are meteorology, hydrology, and oceanography. Due to the close relationship that exists between hydrology and meteorology through the hydrologic cycle, a fairly young offspring, known as hydrometeorology, has been spawned.

The scope of hydrometeorology varies according to the point of view of the person defining it, that is, a semantics problem exists. Many people feel that the true and only study of the hydrometeorologist is the computation of design storm estimates for various hydraulics structures. Others, including most hydrometeorologists, prefer to define it more broadly to include the study of those aspects of meteorology which have the most direct bearing on hydrology and an approach to the solution of hydrologic problems from a meteorological point of view. Linsley, Kohler and Paulhus (1) define hydrometeorology as the study of borderline problems between hydrology and meteorology, and for the present purpose, this "borderline" will be considered to be of considerable breadth.

Natural hydrologic problems can be considered to be of two main types: too little water, or droughts, and too much water, or floods. The application of meteorological theory and data to drought problems will be examined briefly before going on to flood applications.

Evapotranspiration theories permit drought-intensity-frequency analyses as indicated by Robertson (2) and van Bavel (3) to help provide design criteria for irrigation projects. As an example of this, a study was made of seasonal water deficiencies in the Delhi area of southwestern Ontario, using the meteorological data from the Delhi station, to help plan optimum farm

pond sizes and reservoir storage requirements for tobacco irrigation (4). A frequency analysis was performed to indicate the probability of requiring irrigation water volumes greater than any specified amount. Economic and engineering decisions regarding the cost-to-benefit ratio of providing various volumes of water for irrigation can proceed intelligently from the results of this frequency analysis.

Combining meteorological and hydrologic theories and practices can yield methods for river forecasting at low flow periods. Such forecasts have been found valuable in timing the discharge of wastes into streams, to prevent serious water pollution. Meteorological and climatological research has made important contributions to studies of water supply and ground-water fluctuations. However, floods have been the main concern of hydrometeorologists to date.

Hydrometeorological contributions to the solution of flood problems are of two main types: the design of river structures and operational flood forecasting. In design, the first question asked when a new dam, channel diversion or other river structure is being considered is, "How big should it be?" The final answer depends on economic and engineering studies, but any accepted design must be made in the light of estimates of future flood magnitudes on the river, and here hydrometeorology is of assistance. It will be readily appreciated that optimum design criteria (not too big—not too small) are of considerable importance.

The storage capacity of a dam or the carrying capacity of a channel is generally decided by statistical analyses of past flood and storm records. That is, the structures are designed to accommodate, without permitting downstream damage, floods of a specific likely frequency of occurrence, say once in 50 years, or 75 years. These flood magnitudes must be determined by statistical techniques applied to records of past behaviour of the river. Records of the flow of most Canadian rivers are of short duration. In Ontario, a few date back to 1914–15 but most gauges have been in operation only since 1946 or later. Thus in most areas, the precipitation record is much longer than that of run-off, as weather observations, at least in Ontario, frequently date back to the nineteenth century. If good correlations can be developed between stream flow and rainfall (plus snow-melt when applicable) for the period of joint record, then it is possible to "extend" the stream-flow record back to the beginning of precipitation observations. Thus a "design storm" of a given frequency can be converted to a "design flood" and the economic and engineering analyses of a proposed structure can proceed from there.

The discharge capacity of a high dam is a much more critical problem and one for which the basic data are often supplied by the hydrometeorologist. This is particularly true if the high dam is to be built upstream from an urban centre for flood protection. Earth fill construction is often used, and overtopping of a dam would likely result in failure of the structure. Such an event and its accompanying devastation could not be tolerated for

both moral and political reasons. Thus, it is not surprising that the common practice is to design the spillway so that the dam will be able to pass the greatest flow estimated to be capable of occurrence on the river.

In recent years, most estimates of the maximum possible flood on rivers in the United States have been based upon estimates of maximum possible rainfall (plus snow-melt when significant) prepared by the Hydrometeorological Section of the U.S. Weather Bureau under sponsorship of the Corps of Engineers, U.S. Army. An approach based on a meteorological study of the atmospheric factors affecting heavy precipitation is made necessary by the inability of statistical techniques to cope with such a problem. Arnold Court (5) shows that the chance of a ten-year return period flood occurring in any given 100 years is 63 percent. Indeed to design a structure built to last 100 years, with a 95 per cent confidence that its capacity will not be exceeded, requires designing for a 1950-year return period flood. The impossibility of assessing by statistical techniques a flood magnitude of such a long average recurrence interval, from ten to forty years of record, brings meteorological theory into the picture.

The pioneering studies of maximum precipitation carried out by the Hydrometeorological Section of the United States Weather Bureau outline techniques applicable to all parts of North America (6, 7). The basis of their method is storm transposition and maximization. The idea of storm transposition is to increase the meteorological experience of the area studied by considering not only severe storms which have occurred in that area, but also storms which occurred in meteorologically similar adjacent areas. After studying these storms and analysing the rainfall that accompanied them, maximization techniques seek to determine by what factors the actual storm rainfall could have been increased by physically possible increases in the meteorological factors which affect rainfall volume and intensity.

There are two basic types of upward adjustments which could be considered applicable to storm rainfall amounts to obtain probable maximum figures. One is an adjustment for higher moisture content of the rain-producing air mass involved and the other is for greater possible mechanical efficiency of the storm. The latter type of maximization has been found to be impracticable for three reasons given by Paulhus and Gilman(8). (*a*) Little is known of the structure of storms and the factors controlling their efficiency, so the problem of maximization is therefore very difficult to approach. (*b*) Major observed storms have undoubtedly produced heavy precipitation because of their high efficiencies rather than high moisture charge. Thus, a fairly long record of storms over, or transposable to, the area concerned should provide one or more of near maximum mechanical efficiency. (*c*) "It is generally suspected that the maximum efficiency of a storm is realized when the moisture charge is not a maximum." Thus moisture maximization is likely an over-adjustment for this factor and compensates for absence of adjustment to mechanical efficiency.

The basic concept of the moisture adjustment is that, assuming a saturated

atmosphere with pseudo-adiabatic lapse rate, the moisture content of the air mass is a single valued function of the dew point near the ground, or, more specifically, at 1000 mb. This type of moisture and temperature distribution is closely approached in areas of marked convergent flow and upward motion of the air, such as are found near storm centres. This distribution also represents the maximum moisture content of air, of given 1000 mb. dew point, which is undergoing lift to produce precipitation.

The procedure to obtain "probable maximum" rainfall estimates is thus reduced to two steps. First, one obtains the rainfall amounts for various areas and durations observed at the time of major storms that have occurred in the area and meteorologically similar adjacent areas. Then, these amounts are increased by a factor determined by the ratio of the maximum dew point of record in that area, at the time of year of the storm, to the observed storm dew point.

To permit computation of probable maximum rainfall, depth-duration-area analyses of the rainfall of major storms must be available. The U.S. Weather Bureau's Hydrometeorological Section and the U.S. Corps of Engineers meet this need in the United States and publish results on a continuing basis in "Storm Rainfall in the U.S.—Depth-Duration–Area Data" (9). In Canada very little rainfall data have been analysed in this way, although some recent effort has been directed towards this (10). Preliminary estimates of maximum rainfall in southern Ontario for 6 to 48 hours and 10 to 5000 square miles were calculated by making adjustments for maximum moisture content to rainfall of five storms in the United States, transposed to Ontario, and of storm "Hazel's" (October, 1954) rainfall (11).

Maximum precipitation estimates must, of course, be converted into stream flow for a given basin in order to arrive at the probable maximum flood for spillway design purposes. This is done by a study of minimum infiltration rates of the watershed's soils, and the application of unit hydrographs.

It will be necessary to replace gradually the preliminary estimates for southern Ontario with final estimates for each major basin in the region for which high dams are planned. These studies should give due consideration to the shape, topography and geographical location of each basin.

Before final estimates for individual basins in Ontario can be computed, the rainfall of all historical major storms must be analysed and a number of other problems must be investigated more fully. What regions of the United States are "meteorologically similar" to southern Ontario? Do the Great Lakes exert a significant stabilizing influence on air masses moving into southern Ontario and thus inhibit severe thunderstorm development? By how much are rain gauge observations deficient when obtained in periods of strong winds? What orographic effects, other than those of the Great Lakes, are significant on rainfall in southern Ontario? Could heavy winter or spring rainfall, concurrent with a major snow-melt period, produce peak stream

flows in excess of those which the maximum rainfall storm would produce?

The second major phase of the hydrometeorologist's work is his contribution to the development and operation of a system of river forecasting and flood warning. Accurate river forecasts are of value not only in the operation of flood control and water conservation dams on controlled or partially controlled rivers, but also in providing timely flood warnings for the removal of people and goods from the flood plains of uncontrolled streams. For rivers such as those in southern Ontario with drainage basins of 2,000 square miles or less, stream-flow forecasts cannot be made sufficiently far in advance by the routing of observed upstream flows. The forecasts must be essentially "headwater" forecasts based on precipitation and snow-melt forecasts and observations.

While temperature forecasts for a forty-eight hour period are often reliable enough as a basis for snow-melt estimates, the same cannot be said for present-day quantitative forecasts of rainfall. One significant contribution that can be made by hydrometeorologists is to develop reliable methods of forecasting rainfall, or, at least, to prod other research meteorologists to devote time to this problem. While many meteorologists have been, and are, working on quantitative methods of forecasting precipitation, perhaps the most promising development has been the moderately successful attempts of Smagorinsky (12) and others to forecast atmospheric vertical motions and amounts of precipitation by means of high speed electronic computers. However, as yet, quantitative rainfall forecasts are not sufficiently specific or accurate to use in forecasting stream flow.

Thus the hydrometeorologist turns a critical eye to precipitation measurements. Basic observation networks were established by the Meteorological Service of Canada for two main purposes: to obtain synoptic "pictures" of the weather patterns for forecasting, and to establish climatological averages, extremes and trends. The requirements of hydrology are for rainfall observation networks of greater density than those established for the above two purposes, a larger number of rainfall intensity measurements, and more, reliable, measurements of snow-water content.

In southern Ontario, the Conservation Branch of the Department of Planning and Development is attempting to meet these requirements by augmenting the established instrument network. This is being done by means of plastic wedge-shaped rain gauges, automatic weighing-type gauges for recording rain and snow, and snow survey course observations.

The clear plastic gauges are inexpensive, easy to read without emptying the contents and of comparable accuracy to the U.S. Weather Bureau standard rain gauge (13). About fifty have been distributed to volunteer observers who telephone special rainfall observations during storm and flood periods to central offices. Results of preliminary testing of the gauge, in comparison with the Meteorological Service of Canada standard gauge, are very encouraging. A recording rain gauge which does not freeze up in winter and which will measure snowfall water content as well as winter rain-

fall intensities was considered desirable for hydrometeorological purposes in southern Ontario. Weighing-type gauges provided the answer. A number have been installed and equipped with Alter windshields to ensure as accurate as possible snowfall measurements. The tipping-bucket recording rain gauge of the Meteorological Service of Canada, while more sensitive than the weighing-type gauge, is generally inoperative in late fall, winter and early spring as it cannot function in freezing weather. However, the Meteorological Service is at present investigating the possibility of heating these gauges for measuring the intensity of winter rainfall. A move of this kind would be of great value to hydrologists as floods are often produced by intense rainfall in winter and early spring.

Snow survey courses and their values have been the subject of many papers over the past twenty years (14, 15, 16). Suffice it to say, that accurate estimates of water volumes stored in the snow pack for release during melt periods are of considerable value in forecasting spring run-off, on both day-to-day and seasonal bases. Snow survey observations made in eastern Canada are summarized annually by the Meteorological Service (17).

The reliability and accuracy of the catch of a rain and/or snow gauge is often subject to doubt, owing to the effect of wind in creating turbulent air currents about the gauge and preventing a representative number of droplets or snowflakes from dropping into the orifice. This is of much concern when storms produce heavy rainfall with strong winds. A general discussion of the question has been given by Kurtyka (18) and its implications in Canada were discussed at the Third National Meeting of the Canadian Branch of the Royal Meteorological Society (19).

Weather radar will likely be of great assistance in the future in determining the areal distribution of storm rainfall on both an operational and a research basis. In Canada, the weather radar programme is in the process of developing, but the Decca 3 cm. set at Malton airport has already proven its value in tracking paths of heavy thundershowers over southern Ontario watersheds.

Assuming then that weather observations of a reasonable areal density and reliability are available, the preparation of a flood flow forecast involves four steps.

(1) Observed rainfall figures are used to get the average rain depth over the watershed from the storm and snow-melt volumes are estimated when this is significant. In this step, a knowledge of storm types and their characteristic rainfall patterns is important in extrapolating the rain amounts reported to obtain reliable estimates of the average rainfall in a drainage basin.

(2) The run-off volume is forecast from rainfall (plus snow-melt) figures by means of tables based upon previous behaviour of the river which contain factors relating to season and soil moisture content.

(3) The run-off volume is converted into instantaneous flow figures in cubic feet per second for crucial locations on the river. This is usually done by means of unit hydrographs.

(4) Flow forecasts are converted to stage height forecasts giving water levels and their expected times of occurrence. This is done by means of ratings curves relating stage height in feet with flow volumes in cubic feet per second for flood-sensitive river locations.

Meteorological data and knowledge are particularly useful in step 2. Recently developed forecasting methods for southern Ontario streams include a simple technique for forecasting run-off from snow-melt for the Thames North Branch. The number of degree days above 32°F. at London during a melt period are related directly to run-off volume. More complex and reliable methods for forecasting snow-melt have been presented by Clarke (20) for the Red River, and others. These will undoubtedly be valuable guides in developing more sophisticated methods in southern Ontario.

The problem of estimating the percentage of a storm's rainfall which will appear as flow in the main river channels has been approached by developing four variable correlations between rainfall, run-off, antecedent precipitation conditions and the week of the year. These were obtained from records of past storms and floods on the watersheds. It can be seen that the physical realities behind the factors of calendar week and antecedent precipitation include soil moisture content, infiltration rates with various land covers, evapotranspiration, interception of precipitation by foliage, and storage in small depressions. These factors and their interrelationships are of a complexity to cause despair in those developing practical methods of river forecasting. However, in an empirical way, the two indices of antecedent precipitation and week of the year seem to do a good job of synthesizing their effects.

A rainfall intensity factor should be introduced into the correlations. However, to date, such data are too scarce to permit this. An intensive investigation of the meteorology and hydrology of a small representative watershed within the Upper Thames basin is being instituted. It is hoped that refinements in the river forecasting method will result from this study.

While time and space do not permit a complete catalogue of the values and virtues of a meteorological approach to hydrology, or an account of all aspects of hydrometeorological applications in Ontario, it is hoped that some idea of the present and potential scope and importance of hydrometeorology has been indicated.

It is abundantly clear that our water resources and their constructive and destructive powers are of primary importance in Canada's economy. The approach of hydrometeorology to water problems has great potential value in assisting in the wise management of these resources.

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SECTION FOUR

The Distribution and Measurement of Surface Water in Canada

J. D. McLEOD and R. H. CLARK

Presented by R. H. CLARK

ABSTRACT

A continuous long-term record of run-off from any river basin is basic to the planning of an efficient and economic development of the water resources of that basin. The authors outline the history of the organization which has been responsible for the accumulation of surface run-off data in Canada, and some of the problems encountered in the collection and compilation of these data, particularly the effects which the increased utilization of our water resources has had on the organization and planning for the inventory of these resources. Discussed also are some of the problems associated with the distribution and occurrence of precipitation and run-off in Canada and the adequacy of the available data that beset the hydrologist in planning water resource development.

IT is a privilege and a pleasure to be given the opportunity of outlining to you the manner in which data on surface run-off of our Canadian river systems are collected and published, and some of the uses made of these data. The space at our disposal is not sufficient to give you a detailed picture of these activities but, within its limits, we shall discuss generally the occurrence and distribution of surface run-off in Canada and the data requirements in planning water resource developments. A brief history of the organization responsible for the accumulation of surface run-off data in Canada, and some of the problems encountered in planning, collecting and compiling these data are also presented.

Water is the most essential of our resources in maintaining life of any kind upon this earth, and, under properly planned programmes of conservation and development, it forms one of the most important factors in the progress of civilization. Throughout history, water has dominated human life, and history has shown that the growth of any nation is linked very closely to its available water supply. Until recent times, man has not attempted to control water, except in a limited measure for water supply and irrigation. He has, for the most part, adjusted his ways to its vagaries. In his more recent attempts to use science and technical skill to control water to serve his purpose, he has realized the value of an extended history of rivers in the form of stream flow and other hydrologic data.

General Factors Affecting Run-off

Water as found in the lakes, streams and oceans, is being renewed constantly by precipitation in its various forms, and is transported from

place to place in either surface or underground channels. On the other hand, it is being diminished constantly in quantity by the various agencies of percolation, transpiration, evaporation and run-off; these several agencies have widely varying effects from time to time and place to place. Consequently, the amount of water present at any specific time at any particular place is an extremely variable quantity because of the interaction of many inconstant factors.

An example of the great variability of stream flow at a particular place over a period of time occurs on the Red River at Emerson, Manitoba, where the drainage area is approximately 40,000 square miles, and the flow has been recorded systematically for 45 years. The river flow at this station varied from almost zero during several days in February 1937, to about 95,000 cubic feet per second in May 1950, and there is evidence that within the last 150 years there were floods which exceeded this recorded maximum.

The factors affecting stream flow, although they may be subject to direct measurement for any given instant of time, cannot be predicted beyond that instant with any degree of certainty. As a result of this uncertainty of prediction, it is necessary, in all planning for the conservation and development of water resources, to adopt a method that assumes that future variations will follow the same general pattern as past variations. This method involves, as its cardinal principle, the systematic collection and compilation of all data pertaining to water supply for sufficient periods of time to cover the variations that are likely to occur. Among the more important of these data are records of precipitation, temperature, evaporation and run-off. The longer the periods over which a knowledge of the variation of these phenomena has been obtained, the more accurately can the future supplies be predicted. This aspect of our water resources is in sharp contrast to the appraisal of many of the other natural resources. The results of the careful measurement of forest, mineral and land resources of an area provide an index of its natural wealth which usually requires only occasional repetition of the surveys to maintain and improve the accuracy of that inventory.

Regional Variation in Run-off

A synoptic picture of the variation in run-off across Canada can be given on the basis of the five geological regions of Canada: the Canadian Shield; the Appalachian area; the St. Lawrence lowlands; the Great Plains; and the Cordilleran area. Figure 1 delineates these regions and presents the lines of equal mean annual total precipitation in Canada. The variation in precipitation illustrates generally the regional variation in run-off.

The Canadian Shield makes up about two-thirds of the area of Canada and its climate varies from temperate to subarctic. The average annual precipitation varies from about forty inches in the east to ten inches in the far northwest. The topography is confused by numerous lakes scattered

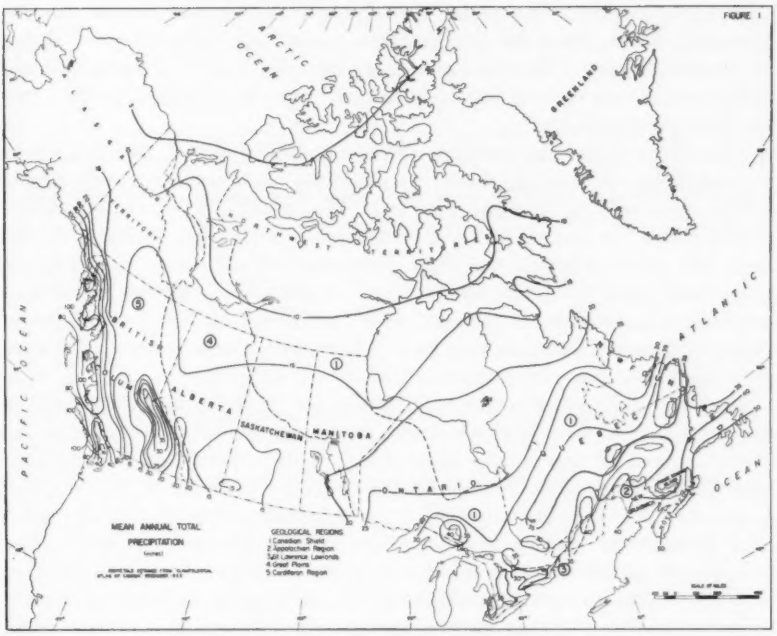

FIGURE 1.—Mean annual total precipitation.

throughout the area and the terrain is generally impervious with ample but irregular gradients. Much of the precipitation, therefore, appears as run-off because the absorption and transpiration losses are relatively small. Evaporation from the lake area is, however, substantial in the summer months. Annual run-off ranges from around twenty-seven inches in the southern portions to less than six inches in the northern sections.

The Appalachian area, which comprises roughly the Maritime Provinces and eastern Quebec south of the St. Lawrence River, reaches altitudes as high as 3,500 feet. The territory is drained by numerous rivers, few of which possess large drainage areas. Precipitation is about fifty-five inches per annum on the Atlantic seaboard, diminishing to about forty inches in the western portion. The combination of relatively impervious terrain, high precipitation and good gradients produces high run-off, averaging on the larger watersheds about thirty-four inches, and, in some cases over fifty inches from the smaller basins in the eastern sections of the region. Further to the west, lower precipitation produces somewhat lower average run-off from twenty-four inches to forty inches, while the mean annual run-off for the Saint John River, by far the largest traversing this region, is more than twenty inches over the drainage area of 15,300 square miles upstream from Pokiok, New Brunswick.

The St. Lawrence lowlands area borders, and is drained by, the St. Lawrence River. Here the precipitation varies from thirty to forty inches per annum. Many of the tributaries carry run-off from the Canadian Shield and Appalachian regions, breaking through into the lowlands to flow into the St. Lawrence River.

The Great Plains are overlaid with great depths of soil, through which streams have cut their channels, ranging from deep coulees to deep, wide valleys, generally on gradual gradients. Precipitation varies from around twenty inches per annum in the east to fifteen inches or less in the south and west. The pervious terrain and slight gradients of the rivers are unfavourable to run-off which, from the purely plains river basins, is generally less than one-half inch, or about 2 per cent of the precipitation. Some of the larger rivers, such as the Saskatchewan, which have their source in the Cordilleran area, have an average annual run-off of about two inches.

In the Cordilleran area, the topographic and climatic conditions vary so greatly that it is difficult to generalize about the run-off. However, on the eastern slopes of the Rocky Mountains, melting snow from the higher altitudes produces run-off varying from about seven inches to twenty-seven inches. In the central belt of plateaux and mountains, run-off varies between wide limits, from around fourteen inches to upwards of forty inches. The western belt of the Cordilleran, including the coastal and insular mountain ranges, receives precipitation which exceeds one hundred inches per annum in the higher altitudes with the mean annual run-off ranging over fifty inches from fairly large watersheds, such as the Nass River basin, of about 6,900 square miles.

A graphical presentation of the variation in run-off from the different regions is shown in Figure 2, which presents annual run-off in inches over the drainage area of a typical stream from each region for a twenty-year period, 1930–49. The unit run-off from a purely plains river, such as the Assiniboine, is in sharp contrast to the streams from the other geological regions. As a matter of interest, the average monthly hydrograph for each of these typical streams is also shown to indicate the average variation of the flow during the year.

The run-off of Canada falls into five major slopes or watersheds, namely, the Atlantic slope, the St. Lawrence River watershed, the Hudson Bay slope, including the central prairie region of the Nelson River watershed, the Arctic slope, and the Pacific slope. The field studies of the hydrometric survey are planned and the run-off data systematically published to conform with these natural run-off divisions. These stream measurement reports provide the fundamental records upon which to base all undertakings relating to the use of water.

History of the Hydrometric Survey

A hydrometric survey involves the measurement, compilation, analysis and publication of the records of the flow and level of water in rivers,

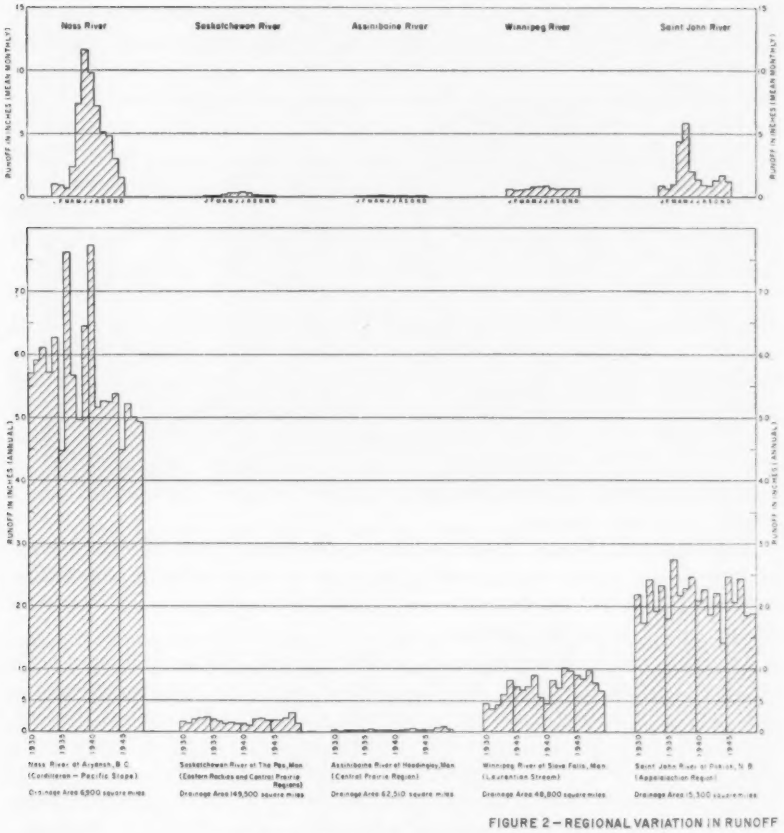

FIGURE 2.—Regional variation in run-off.

streams and lakes. The Water Resources Branch of the Department of Northern Affairs and National Resources has as one of its primary functions the maintenance of the systematic hydrometric survey programme in operation across the nation.

The history of the hydrometric survey in Canada began in 1894 when some stream measurement work was performed in connection with the irrigation surveys made by the Forestry Branch of the Department of the Interior. In 1908 the federal Parliament made its first specific appropriation "for gauging streams and determining the water supply in southern Alberta and Saskatchewan" and for this purpose the Hydrographic Survey was established in 1909 with headquarters at Calgary, Alberta. The year 1911 saw the establishment of the Dominion Water Power Branch under which were consolidated the hydrometric survey programme already in operation

for the irrigation requirements, the water power investigations under way on the Winnipeg and Bow rivers, and the administration of water power on Dominion lands. In 1913 arrangements were made with the Government of British Columbia under which the hydrometric survey programme for that province was continued by the Dominion Water Power Branch, although administration of nearly all water resources passed to the province. Subsequently, similar arrangements were made with Nova Scotia, New Brunswick, Ontario, Quebec and Prince Edward Island. Until 1930, however, the administration of the natural resources of the three Prairie Provinces was in the hands of the federal Government, but at that time this administration was transferred to the respective governments of Alberta, Saskatchewan and Manitoba; and, as in British Columbia many years earlier, the operation of the hydrometric survey programme remained with the Dominion Water Power Branch. These arrangements were altered to some extent during the depression years of the 1930's but continued in force in all provinces except Prince Edward Island where the topography and regimen of the streams limits the possibilities of extensive river development very considerably. A similar arrangement was made with the province of Newfoundland on its advent into Confederation.

The Dominion Water Power Branch of the Department of the Interior underwent numerous changes of name prior to 1956 when it was finally changed to the Water Resources Branch of the Department of Northern Affairs and National Resources.

The hydrometric survey programme today literally spans the nation with data collected on rivers and lakes from the Yukon Territory to Newfoundland. The programme is carried on through six District Offices and thirteen sub-offices of the Branch. Data are collected at nearly 1,200 different locations and the results are published in biennial Water Resources Papers. These records vary from continuous observations of levels on principal rivers and lakes, reduced for publication to mean daily values of flow or elevation, to intermittent observations of level or miscellaneous measurements of flow on lakes and streams in isolated areas or where current requirements are for a minimum of information.

Some Factors Involved in the Establishment and Maintenance of Stream Flow Stations

As an illustration of the work involved in the operation and maintenance of a hydrometric survey, let us take the example of determination of the flow of a river. The first step is to make a reconnaissance survey of that reach of the river in the vicinity of the location where the flow information is necessary. This may be accomplished by boat, but frequently involves foot travel. On a river in its natural state, there is normally a definite relationship between the level or height of the water at any given point and the flow or amount of water passing that point. Where this relationship

FIGURE 3.—Catamaran used in discharge measurement programme (winter of 1954–55) on the St. Lawrence River (about six miles downstream from Morrisburg, Ont.).

exists, it is possible to define it by making a series of measurements of the flow at different river levels. It is necessary, therefore, on the reconnaissance or first trip to the river, to select the best possible location for a gauge which will indicate the level or height of the river, and a cross-section of the river where accurate measurements may be made. Once these have been selected, the engineer must decide on the particular type of gauge to be built and also on the equipment for measuring the flow; if the river is shallow it may be possible to measure the stream by wading; if it is very wide and cannot be obstructed due to traffic, boats may be used; if there is a railway or highway bridge in the vicinity, it may provide an adequate place for measurement; but, if all of these possibilities fail, it becomes necessary to consider the erection of a cableway and a cable car from which measurements may be made. Illustrations of several of these methods used on some of our larger rivers are shown in Figures 3, 4, 5 and 6. Figure 7 illustrates the type of structures built on the more important streams to house the equipment which will provide a continuous record of water levels throughout all seasons.

On his return to the office from this reconnaissance trip, the engineer has to report his findings to the District Engineer. When the type of gauge and measurement structures has been selected, the engineer is called upon to produce a satisfactory and economical design together with plans and specifications. When the materials are ordered and the working force for construction recruited, the engineer returns to the site and supervises the erection and installation of the required structures and equipment.

FIGURE 4.—Mercier Bridge over the St. Lawrence River near Montreal, P.Q. (winter of 1955–56).

After the foregoing procedure has been completed, the engineer must locate some resident of the area who will read the gauge at periodic intervals, daily, weekly or as required at the particular location. For this purpose the Branch employs about 500 gauge observers on a part-time basis. Each observer is provided with forms and stationery on which he makes his reports to the District Office. If the location is very remote, periodic observations have to be made by personnel from the District Office.

During the first year of operation of the gauging station, it is necessary for the engineer to make frequent measurements of the flow to establish its relation to the level of the river. Once this relationship has been established it is necessary to check it by measurement at periodic intervals to ensure that no change has taken place. Changes in the relationship arise from a variety of conditions, such as erosion of the river banks, deposition of silt or gravel in the river bed, or artificial changes in the channel.

When the observer has forwarded his readings to the office and the results of the engineer's flow measurements are available, work is commenced on computing the flow records for the gauging station. The first step is the establishment of the relationship between the level and the flow of the river at that point and its conversion to tabular form for efficient office use. The observer's readings are then checked and converted to flow figures, usually for each day of the year. These figures are compiled on special forms and monthly and annual averages determined. All of the working data are then completely checked, item by item. The manuscript for publication is prepared from the checked information. Incorporated with this information is a description of the gauging station which denotes its location, its equipment,

FIGURE 5.—Motorized crane used for discharge measurements and soundings from Mercier Bridge.

the greatest and smallest flows recorded, and other pertinent facts. This manuscript copy is assembled and forwarded to the Head Office for rechecking and final preparation before printing. It appears, finally, on two or three pages of one of the Water Resources Papers, which are published at two-year intervals to make such basic information available to all who work on water problems. For purposes of publication Canada is divided into four major drainages: Pacific, Arctic–Western Hudson Bay, St. Lawrence–Southern Hudson Bay, and Atlantic.

The foregoing brief summary gives only the highlights of a simple straightforward example of gauging station installation and operation. Even as water itself is never chemically pure outside of the laboratory, the conditions of its flow in our rivers and lakes are never ideal for accurate measurement. Many of these conditions make the task of securing adequate information a complicated one indeed.

PLANNING A HYDROMETRIC SURVEY PROGRAMME

Total stream flow from an area represents in most cases the upper limit of water potentially available for sustained development from both surface and underground sources. Stream flow is the integration of all factors as they affect the movement of water through and over the land. It is the last link in a long chain of events.

Important uses of surface water are made in natural and artificial channels for navigation, production of hydro-electric power, irrigation, domestic

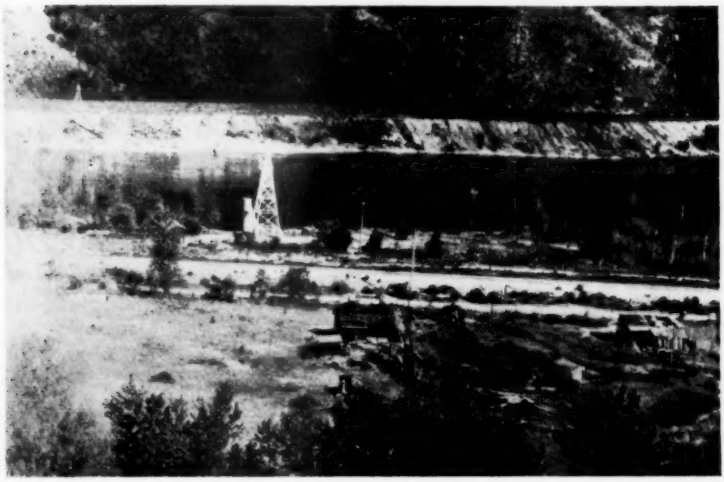

FIGURE 6.—Cableway with car for discharge measurements of the Columbia River at Birchbank, B.C. (about six miles upstream from Trail).

and recreational purposes and the dilution of wastes. Most of these uses of surface water are made possible by structures for the regulation and distribution of stream flow. Flood protection, for example, requires control works such as dams, reservoirs, dykes and floodways, and stream flow data are essential to the efficient design of these elements of a flood control plan.

Hundreds of millions of dollars have been spent already on the development of Canada's water resources, and there is little doubt that expenditures for protection against floods and droughts, and for the development of irrigation, power, water supply, recreation and navigation will expand to meet the enlarging requirements of an increasing population and of growing industries. Further development will require more detailed and precise information for more comprehensive programmes.

A basic requirement for the planning of effective water-use projects is the availability of adequate surface-water flow and level information. The lack of such information may result in projects being over-designed with a resultant waste of money and possibly a failure to fulfil the original purpose of the project. Similarly, the lack of information may result in under-design of a project which is even more critical than over-design as it may result in hazard to life and property. Everyone is aware of the damages caused by floods such as those which occurred in the lower Fraser River valley near Vancouver in 1948, in the Red River valley, particularly at Winnipeg, in 1950 and in the Humber River valley in and near Toronto following hurricane Hazel in 1954. In each of these cases many bridges were destroyed, culverts were washed out, railway and highway embankments were undermined and there was a general dislocation of facilities. Each destroyed or

FIGURE 7.—Water-stage recorder well and shelter on the Fraser River at Hope, B.C.

damaged bridge, culvert, railway or highway, represents an instance of under-design, chiefly through lack of knowledge of the maximum flood to be anticipated in the area.

Although Canada has been fortunate in having no recorded failures of large dams, an occurrence of this nature, which could happen if a project were under-designed, might result in damage or loss not only of the structure but of all forms of cultural foreshore development downstream and even of human life.

A typical example of water-use planning occurs when a reservoir is proposed for a town water supply. Foremost among the requirements of the design engineer would be the need for a long continuous record of stream flow to provide the data for determination of the size of the reservoir. Is its capacity greater than the stream flow potential? Is it expected that the reservoir will be empty once, or perhaps twice in the next fifty years? What size of spillway should be provided for the dam to ensure that the structure will not fail under a severe flood and cause damage and loss of life? These are but a few of the questions for which adequate stream flow records would provide the answers. The efficiency of reservoir regulation is dependent upon the duration of low flows and its safety upon the relation of the spillway capacity to the maximum flows. If flow records on a particular stream are meagre or non-existent, the hydrologist, in planning and designing a water resource development, must rely on such hydrologic studies as correlations with long-term data on neighbouring streams, correlations with rainfall data which usually are available for longer periods of time than run-off data,

supported by spot discharge measurements and ground-water investigations. The results of these substitute studies are never quite as dependable as actual records.

Analyses of actual stream flow records give the only reliable information on floods, flood frequencies, total flow, maximum flow, minimum flow and time-duration of flow. Long-term stream flow records from a basic network of gauging stations are fundamental to such hydrologic analyses. Continuity is vital because of the variability of run-off in place and in time, and the possibility of maximum floods and extremely low flows within a brief period.

It has been stated repeatedly that records of stream flow must extend continuously over a considerable span of years in order that the regimen of the stream may be understood in sufficient detail to permit adequate project planning and designing. There follows from this the basic question of what factors determine whether measurement of a particular stream or streams should be undertaken. Perhaps the best answer to this question may be provided by illustration.

The formation of the Dominion Water Power Branch in 1911 marked the advent in Canada of hydrometric surveys on a systematic basis. This Branch took over the operation of a number of stream flow and water level stations established previously to meet requirements for information about surface water flow at a number of specific locations. At the same time numerous river systems were subjected to preliminary reconnaissance which determined approximately the concentration of head and the location of reservoir possibilities that formed the topographical elements of the hydro-electric power potential of the rivers. Stream flow and water level stations were established at as many locations as possible to provide the data needed in conjunction with the topographical information to assess these power potentials.

At that time also, river and lake navigation was exceedingly important particularly in offering the only means of transportation in many of the more remote areas. As a result, gauges were established to record water levels for navigation as had been done on the Great Lakes and St. Lawrence River beginning in 1860. Flow records were also required in numerous locations in connection with proposals for irrigation development, particularly in the region now forming part of southern Alberta and southern Saskatchewan. Some of these latter proposals involved international water problems also, as, for example, that of the division between Canada and the United States of flow of the St. Mary and Milk rivers.

From the foregoing it will be seen that most of the programme of operations by the Dominion Water Power Branch was determined by the needs which had led to the formation of the Branch. The assumption by the various provinces of the rights to the water resources within their boundaries has led to investigation, in varying degree, of the development possibilities by each of the provinces and has resulted also in a great many requests for additional information about stream flow and water levels.

In addition to these factors which determine the bulk of the hydrometric survey programme, the need for lengthy periods of record as a basis for efficient development has made it essential that the hydrometric survey operations commence as soon as possible after preliminary exploration of the more remote areas of the country. As a result, the last decade has seen the expansion of these operations into the Yukon Territory, Ungava and Labrador and their continuation and further expansion in the more settled and populous regions.

The foregoing requirement makes it necessary that the hydrometric survey be somewhat of a pioneer operation and, hence, that one of the major operational problems is that of access. At the present time the bulk of the transport requirements for hydrometric surveys is met by the use of automobiles and light trucks, but the more remote locations are reached by boat, snowmobile, aeroplane and helicopter, with occasional use of dog teams and pack horses. Oddly enough, helicopter transportation is used to reach a river measurement station which is not more than 50 miles by air from the third largest city in Canada, but which could be reached otherwise only by several days of most arduous travel, chiefly on foot. As the hydrometric survey programme is extended further into the remote areas, particularly in northern Canada, air transport, both conventional and helicopter, will become increasingly useful.

The hydrometric survey differs in operation from other surveys in one major respect: much of the field work must be done during the winter season. The regimen of many of our rivers is such that minimum flows occur during the winter period; but the prospective demand for the use of these flows is frequently at its maximum during the winter, particularly when the water is used for generating hydro-electric power. This requirement adds greatly to the difficulties inherent in the field operations of the hydrometric survey as the handling of precise survey instruments at temperatures as low as —45°F becomes awkward and hazardous.

In recent years efforts have been directed to expanding the hydrometric survey programme in advance of immediate requirements. These efforts have to be sufficient to satisfy all of the needs of Canada's rapidly expanding economy but in some areas it has been possible to anticipate needs and provide for them, at least to a limited extent. For example, a preliminary reconnaissance for power potential was made on the Yukon River in 1915 and a few miscellaneous records of stream flow and water level were collected at that time. It is unfortunate that a basic programme was not in operation continuously from then until the present day. However, with the completion of the Alaska Highway in 1943, a skeleton programme covering the establishment of gauging stations was begun on the Yukon River and several of its tributaries as well as on the Liard and Peace rivers in northeastern British Columbia, and records are now available from several stations in the Yukon River system since 1944. The first specific request for these records occurred about 1948 with the planning of a diversion of water from

the upper Yukon River system to the Taiya River for a large power development in the panhandle of Alaska. This alienation of Canadian water resources was not allowed by the Government of Canada but in 1952 Frobisher Limited, through its subsidiaries, began investigations of a similar proposal by which the power would be developed at sites on the Taku River system in northwestern British Columbia. This proposal envisages the development of some four million horsepower, chiefly for use in metallurgical processing and such other industry as might be located in that region. While it was necessary to install additional gauging stations at a number of locations to provide all of the flow information required, it is significant that the eight years of record then available on the Yukon and Teslin rivers were sufficient to determine preliminary estimates of what might be accomplished in the way of power production by diversion of these waters. These basic records were also helpful in correlation with other data to learn what amount of run-off might be expected from various portions of that part of the Yukon River basin involved in the over-all proposal.

A somewhat similar instance occurred on the opposite coast of Canada in the remote area of Labrador. Prior to the entry of Newfoundland into Confederation, exploration had disclosed the existence of immense hydro-electric power possibilities on the Hamilton River, particularly at Grand Falls. When Newfoundland entered Confederation this Branch assumed responsibility for hydrometric surveys in Newfoundland and Labrador and took over several members of the Newfoundland government staff who had been engaged in similar activities. Shortly after, a gauging station was installed on the Hamilton River at Muskrat Falls. This was a most difficult and expensive installation to complete chiefly because of the limited access facilities and the lack of any cultural development whatsoever in the region. Subsequently, the British Newfoundland Corporation by agreement with the Government of Newfoundland arranged to survey a large portion of Labrador to assess the natural resources, particularly forest, mineral and water power. Under co-operative arrangements with that Corporation, the Branch established several additional stream flow and water level stations on the upper Hamilton River system which were much more effective in providing information as there was already a location downstream where some records were available.

Adequacy of data cannot be defined once for years to come. The use for which stream-flow information is sought will vary from time to time as needs expand or change. As an example, the Branch has collected such records at many points in central and northern Ontario for periods of up to forty years. These records were required primarily to determine the hydro-electric power potential of these rivers, many of which provide feasible sites for production of hydro-electric power. During this period the southern Ontario area was developing rapidly, particularly as the centre of Canada's industrial activity, and acquiring the greatest population density of any area of similar size in the nation. Numerous floods had been experienced on the many small rivers which drain the area but the residents accepted these as part of the

hazards of living there. The continued increase in cultural development and, in particular, foreshore development, caused the damages from these floods to increase very materially and gradually a change in the thinking of the residents took place. Where once the occurrence of floods had been accepted as part of the living conditions of the area, this condition was no longer tolerated without protest. The Government of Ontario passed a conservation act under the terms of which municipalities within a river basin could band together in establishing a conservation authority to determine what remedial action might be taken to control flooding and to contribute to the conservation of water for use in summer periods. A number of these conservation authorities were formed and arrangements were made for the construction of dams on several of the rivers, the cost being defrayed jointly by the governments of Canada and Ontario and by the affected municipalities through their respective conservation authorities. Examples of these developments include the Shand, Luther-Marsh, Fanshaw and Conestogo projects. The planning of these and other projects disclosed the paucity of adequate stream flow and water level records for this purpose. The result has been that, during the past four years, the Branch has put into operation some fifty additional gauging stations in co-operation with the Ontario Department of Planning and Development. However, these will not compensate for the lack of earlier records until they have been in operation for an appreciable number of years. It is unfortunate that the requirements of this nature could not have been foreseen, say, twenty years ago, but it does provide an excellent illustration of the change that may take place in needs for flow and water level data.

Brief reference has been made to co-operation of the provincial water resource authorities with the Branch in planning and operating the hydrometric survey programme. The advantages of having all work of this nature done by one agency are obvious as, first, such a procedure results in more uniform methods of collection and compilation of data and, secondly, many streams are interprovincial and so the records obtained in one province are of interest to another province. The Saskatchewan River, which has its headwaters in Alberta and flows eastwards through Saskatchewan and Manitoba to enter the Nelson River system and so reach the sea in Hudson Bay, is an example of an interprovincial river on which records obtained in Alberta are of interest to Saskatchewan and Manitoba also. Similarly, records obtained on the upper reaches of the Ottawa River in Quebec are valuable to Ontario power interests.

The federal Government controls the water resources in the Northwest Territories. While settlement and cultural development of this area has been slow, it now is proceeding at an accelerated rate owing principally to its extensive mineral resources, to defence requirements, and to the current policy of the Department of Northern Affairs and National Resources to develop these northern areas and to bring education, health and greater opportunities to the native population. A quantitative knowledge of the

water resources of this vast region north of the 60th parallel is essential to the over-all development of the northland where the extensive lake and river systems provide much of the transportation facilities for bulk commodities and where the supply of hydro-electric power will play an integral part in the production of mineral and petroleum products.

Another reason for more information in a part of Canada's northland is the existence of the International Boundary between the province of British Columbia, the Yukon Territory and Alaska. Undoubtedly the growth of the cultural development of the regions drained by the rivers which cross this Boundary will result in international waterway problems similar to those which have been encountered elsewhere along the International Boundary between Canada and the United States. An integral element in the analysis and solution of these problems will be the supply of adequate data of stream flow and water levels.

With these factors in mind, the Branch is endeavouring to plan an orderly expansion of the systematic hydrometric survey programme to cover the key points on the river systems of the Canadian north. This, the last frontier area of the nation, may be expected to develop during the next century in a manner somewhat similar to the development which has taken place in western Canada during the last century.

TRANSACTIONS OF THE ROYAL SOCIETY OF CANADA
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SECTION FOUR

Status of Ground-Water Studies in Canada*

KEITH POLLITT
Presented by C. S. LORD, F.R.S.C.

ABSTRACT

Ground-water studies in Canada were initiated by the Geological Survey of Canada in 1903. Investigations during the first thirty years were confined almost solely to the provinces of Manitoba, Saskatchewan, and Alberta. More recent surveys have embraced nearly every province in Canada.

The provinces of Alberta, British Columbia, Ontario, and Quebec carry on ground-water studies which are independent of federal programmes. Ontario was the first to enter the field in 1945.

Ground-water studies are a necessity for a full understanding of the hydrology of Canada and so are essential in the planning of settlement and industry in our country.

THE first known ground-water studies in Canada were made by the Geological Survey of Canada. The Borings Division of the Geological Survey, organized in 1908, was made responsible for the study of Canada's ground-water resources in addition to its duties in the field of oil, gas and coal. In 1945 the investigations became part of the programme of mapping Canada's glacial deposits, and have remained with the Pleistocene and Engineering Geology Division since that time, with the exception of a two-year term with the Fuels and Stratigraphic Geology Division. Although the first ground-water survey was made by the Geological Survey in 1903, these studies did not become continuous until 1945. For the most part, investigations from 1916 to 1950 were carried out in connection with mapping the Pleistocene deposits. Since 1950 work has continued independently of either surficial or bedrock mapping. The surveys are essentially areal or reconnaissance in nature, data being obtained through an inventory with well owners and drillers. Aside from the regular programme, the Ground Water Section undertakes special projects at the request of federal departments and agencies. Of great value to those in search of buried stream valleys is the work being carried out in southern Ontario by the Fuels and Stratigraphic Geology Division of the Geological Survey. Here thicknesses of glacial drift are contoured from data made available through records of wells drilled for gas and oil. The present staff of the Ground Water Section of the Geological Survey comprises five men, only three of whom are actively engaged in ground-water studies in the field.

Four provinces are currently active in the field of ground-water explora-

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tion. Although other provinces may have, from time to time, made a few investigations, only Ontario, Quebec, Alberta and British Columbia now have continuing programmes. The province of Ontario was the first to enter this field, in 1945.

Only regional studies throughout Canada will be discussed in this paper although it should be realized that the Geological Survey of Canada, as well as other agencies both federal, provincial and municipal have at various times conducted special investigations in a number of localities. These individual studies would be too numerous to mention. Ground-water studies carried out by the Geological Survey will be discussed first.

The first area investigated by the federal Survey was the Island of Montreal in 1903. The published report was based on records of wells drilled almost entirely in the city of Montreal. The second ground-water survey, in 1912, covered the same area and again the report was based mainly on records of industrial and commercial wells in the city. Between 1916 and 1932, several areas in southeastern Alberta and in southern Saskatchewan were investigated, including the cities of Regina and Moose Jaw. Subsequent work in these two provinces included each of the previously surveyed areas. Between 1916 and 1918 and between 1926 and 1929, the ground-water resources and surface deposits were studied in an area of over 46,000 square miles in southern Manitoba extending north from the International Boundary to latitude 52°. In 1933 and 1934 a survey of ground-water conditions in the Ottawa area was made.

Drought conditions in Western Canada in 1933–4 which caused acute shortages of water prompted, in 1935, the most elaborate programme of ground-water investigation ever carried out by the Geological Survey. The magnitude of the project may be realized by the fact that, in Saskatchewan alone, 84,000 square miles were under investigation in two separate areas. The larger area extended north from the International Boundary to approximately latitude 52° and comprised 72,000 square miles. The smaller area of 12,000 square miles extended from the northern boundary of the above area to latitude 54° and was confined to the western section of the province. At the same time ground-water data were being collected over an area of 22,000 square miles in east-central Alberta. It is noteworthy that, of a total of 312 Geological Survey Water Supply Papers published to date, 275, or almost 90 per cent, concern the work carried out in 1935.

The following year, 1936, saw the work in Western Canada confined to southeastern Alberta. In the same year ground-water resources of Ontario were studied for the first time. In 1936 and 1937 the area concerned nine townships between Toronto and Lake Simcoe. Between 1937 and 1945 no ground-water survey parties were placed in the field. The year 1945 saw an investigation of ground-water conditions in the first of several townships to be studied in the Lake Simcoe district of Ontario. Between that year and 1949 work was completed in twenty-two townships. Beginning in 1946 and continuing through 1950 water well data were collected in east-central

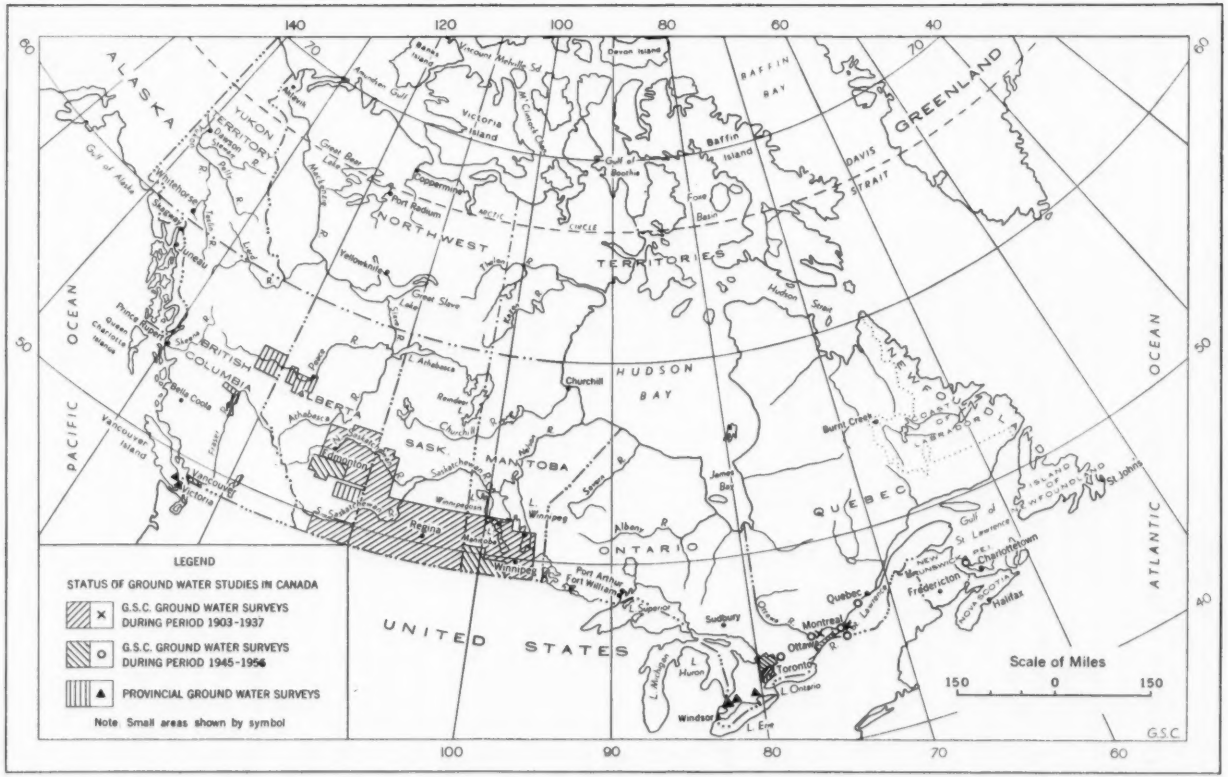
LEGEND
STATUS OF GROUND WATER STUDIES IN CANADA
G.S.C. GROUND WATER SURVEYS DURING PERIOD 1903-1937
G.S.C. GROUND WATER SURVEYS DURING PERIOD 1945-1956
PROVINCIAL GROUND WATER SURVEYS
Note: Small areas shown by symbol
Scale of Miles
150 0 150
G.S.C.
ALASKA
YUKON TERRITORY
NORTHWEST TERRITORIES
GREENLAND
BRITISH COLUMBIA
ALBERTA
SASK.
MANITOBA
ONTARIO
QUEBEC
HUDSON BAY
BAFFIN BAY
DAVIS STRAIT
PACIFIC OCEAN
ATLANTIC OCEAN
UNITED STATES
Victoria Island
Baffin Island
Vancouver Island
Prince of Wales Island
Queen Charlotte Islands
Great Bear Lake
Great Slave Lake
Athabasca
Churchill
Winnipeg
Superior
Huron
Ontario
Erie
Whitehorse
Yellowknife
Edmonton
Regina
Winnipeg
Port Arthur
Fort William
Sudbury
Ottawa
Montreal
Quebec
Toronto
Windsor
Fredericton
Halifax
Charlottetown
St. Johns
Churchill
Burnt Creek
James Bay
Gulf of St. Lawrence
Labrador
Newfoundland
Nova Scotia
New Brunswick
P.E.I.
140
120
100
80
60
40
80
70
60
50
40
100
90
80
70
60

FIGURE 1.

Alberta adjacent to previously investigated areas. Southwestern Manitoba was studied in detail between 1946 and 1953.

In 1949 and 1950 an area was examined bordering the north shore of the St. Lawrence River between Prescott, Ontario, and the Quebec boundary. During the same years the ground-water resources of the northwestern section of Prince Edward Island were studied. In 1950 and 1951 an area on the shores of the St. Lawrence River between Montreal and Quebec was the object of a ground-water investigation. In 1951, studies of the ground-water resources of the Montreal and Ottawa regions were begun. The work in Montreal included the entire Island of Montreal and was completed in 1953; while the Ottawa area comprising Gloucester and Nepean townships was concluded in the previous year.

Two projects are currently under investigation. One is a study of ground-water conditions in the Lower Fraser valley of British Columbia, a programme initiated in 1950 which is the most comprehensive ever undertaken by the Geological Survey. The other project borders the St. Lawrence Seaway, studies having commenced in 1955 at Montreal. Work is currently being extended along the river to join the 1949–50 survey at the Ontario boundary.

The results of all investigations by the Geological Survey of Canada are available to the public. Ground-water reports have been published for most of the surveyed areas while unpublished records of certain areas may be consulted in Ottawa by interested parties. Aside from data collected during the many areal surveys, the Ground Water Section of the Geological Survey has on file records of water wells from all parts of Canada.

Mention has been made that four provinces are currently active in the field of ground-water exploration. In 1945, the province of Ontario organized a Ground Water Survey under the jurisdiction of the Department of Mines. Toward the start of the programme, observation wells were established throughout the province, some of which were equipped with automatic water level recorders. Field projects have been confined for the most part to southwestern Ontario where the demand is more acute for adequate supplies of ground water for industries and municipalities. Investigations have been made in the townships of North York, Etobicoke, Chinguacousy, Toronto, Windham, Woodhouse, Mosa and Camden Gore. In 1946, legislation was enacted in Ontario whereby water well drillers were licensed and each driller was required to complete and file with the provincial Ground Water Survey a report, including logs and test pumping data, on all wells drilled. The Ontario Water Resources Commission formed over a year ago recently incorporated the Ground Water Survey. The commission is responsible for conducting research into the availability of water, from both surface and underground sources, for municipalities and other communities.

Ground-water studies in British Columbia began in 1950. Areas surveyed between 1950 and 1953 were the Peace River block in the northeastern section of the province; the agricultural districts in the Quesnel–Prince

George–Vanderhoof areas and sections of the eastern coastal lowland of Vancouver Island. Between 1954 and the present time, ground-water investigation has been confined to the Okanagan Valley of south-central British Columbia.

The Alberta Government has not, until this year, had a continuing ground-water programme. The Research Council of Alberta expects to place at least five ground-water parties in the field in the near future in an attempt to solve water supply problems of communities. To date, two studies have been made by the province: the first in 1929 in the Peace River and Grande Prairie districts, the second in 1946 in the Sounding Creek area of southeastern Alberta. The Government of Alberta has a Ground Water Control Act similar to the Water Well Drillers Act of Ontario. The act is designed to prevent wastage of ground water with particular respect to flowing wells; to collect information on ground-water supply through drillers' reports; and to provide for the licensing of water well drillers.

The ground-water programme of the Quebec Geological Survey has not, as far as is known, involved any mapping or areal studies. It has been concerned with attempting to solve specific ground-water problems by individual investigation. These problems for the most part concern water-short communities. Ground-water studies in Quebec began in 1949. The division is also responsible for the logging of deep borings for oil and gas.

With the exception of the 1929 ground-water project in Alberta, all provincial studies began after the Second World War. In most cases, ground-water surveys in the four active provinces have been, and are still being, carried out in conjunction with mapping glacial deposits.

Ground-water problems exist in Canada today as in any other country in the world. Perhaps they are not quite as obvious here since this country is fortunate enough to have 7 per cent of its total area occupied by rivers, streams and fresh water lakes. More acute ground-water shortages have in the past been evidenced in the Prairie Provinces and in southwestern Ontario. These shortages will in time spread to other parts of the country and new problems, such as salt water encroachment along our coasts, will become more pronounced. Changes in the natural balance of the hydrologic cycle have been brought about by draining swampy areas, deforestation, and poor and improper methods of cultivation. These changes have caused excessive run-off, soil erosion, flash flooding and drying of streams during summer months. Overdraft created by over-pumping by large users of ground water is bound to create serious problems in the future. Increased demands for ground water by many large municipalities, particularly in southwestern Ontario, are straining waterworks systems to their limits. That this problem is being realized is indicated by the recent formation of the Ontario Water Resources Commission mentioned earlier. The commission will seek to aid municipalities and communities in their search for water and, if the need arises, will supervise construction of pipe lines designed to carry water from the Great Lakes. The fact that the province of Alberta intends to place five

ground-water parties in the field in the near future, as well as two or three other groups whose work will be indirectly associated with ground water, indicates the importance being attached to the many and far-reaching difficulties which must be surmounted in the search for abundant water of suitable quality.

Future development in Canada will bring increased demands for water by municipal, industrial, domestic, farm and irrigation users. Population and industry cannot all be concentrated near the Great Lakes or near major streams and other lakes. Many of the above users will have to depend upon ground water for their needs and although this water is a replenishable resource it is available only in limited quantity, dependent entirely upon precipitation. Withdrawal of water from the underground reservoir in excess of the annual recharge in any drainage system will deplete the available supply.

It is necessary, therefore, that ground-water studies in Canada not only be continued but also be expanded to promote a better understanding of the hydrology of Canada. More research is necessary on specific problems in specific areas thus involving more detailed study. The object of this work is to properly assess our ground-water resources, to attempt to determine how much water is likely to be available in any particular region and whether or not we may be able to supply the inevitable increased demand for water.

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